Project ID # VAN023

Assessing Energy and Cost Impact of Advanced Vehicle Technologies

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**2020 DOE Vehicle Technologies Office
Annual Merit Review**

June 2020

Project Overview

Timeline	Barriers*
• Project start date : October 2019 • Project end date : September 2022 • Percent complete : 20%	• Risk aversion • Constant advances in technology • Cost • Computational models, design, and simulation methodologies *from 2011-2015 VTP MYPP

Budget	Partners
• FY20 Funding : $300K • FY20-22 Planned Budget: $900K	• NREL (drive cycles) • U.S. DRIVE Partners • 21 CTP Partners • U.S. DOT / NHTSA • Outside companies (OEMs, suppliers…)

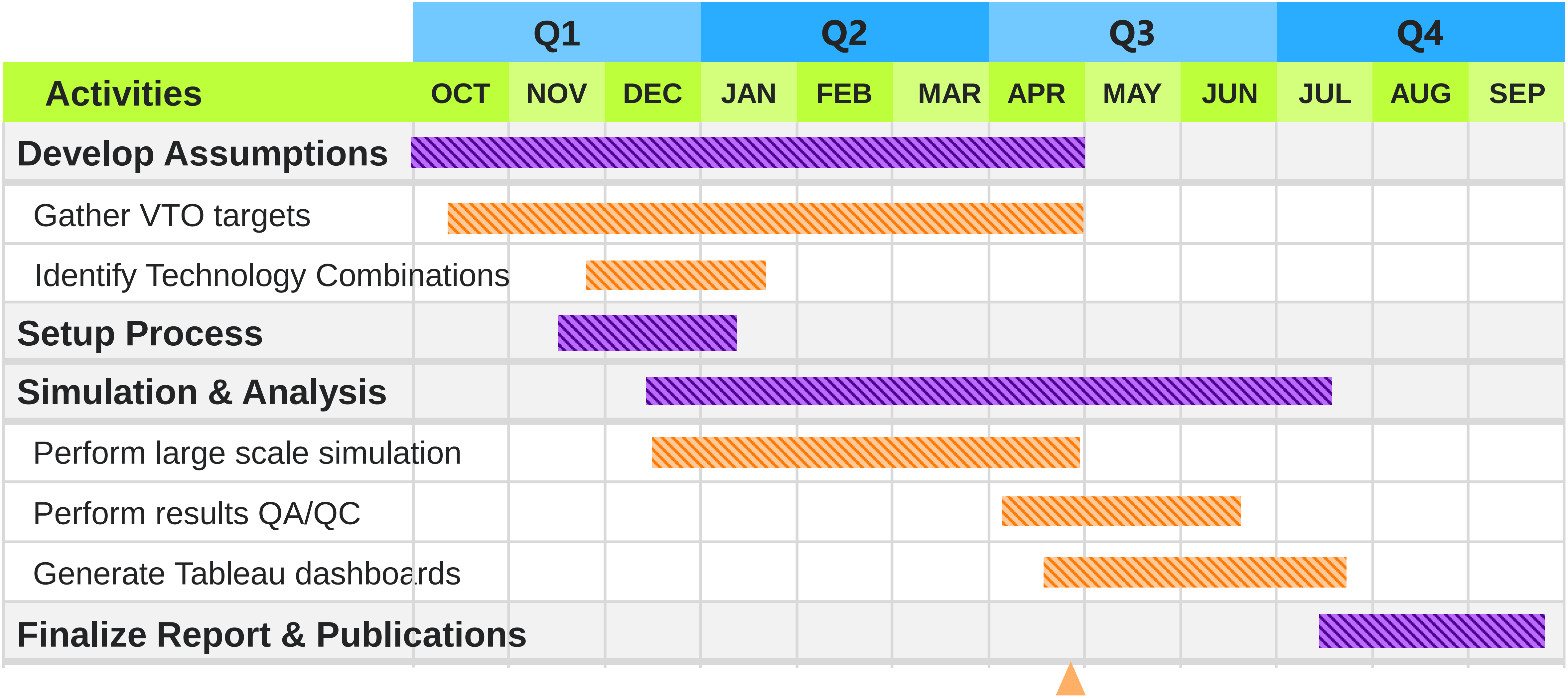
Objectives & Relevance

What are the fuel saving benefits and economic impacts from VTO funded technologies?
What are the Total Cost of Ownership (TCO) impacts?

- **Task 1**
  - Quantify the contribution of specific vehicle technologies on energy consumption and cost
    - Develop a generic process that could be used for all classes and vocations
    - Apply the process to midsize car for selected timeframes
- **Task 2**
  - Quantify the benefits of vehicle technologies on light duty vehicles, medium & heavy duty trucks
    - Update assumptions for latest vehicles (model year 2020)
    - Update vehicle models, powertrain architectures
    - Add new vehicle requirements & update sizing methods (developed with inputs from 21CTP, a consortium of OEMs, Suppliers and DOE)

- **Disseminate data:** Provide the database of vehicle and component characteristics along with the related assumptions for wider research use.
- This work provides feedback to DOE managers about implications of the technology targets and supports multiple related studies including market penetration and life cycle analysis

FY20 Milestones



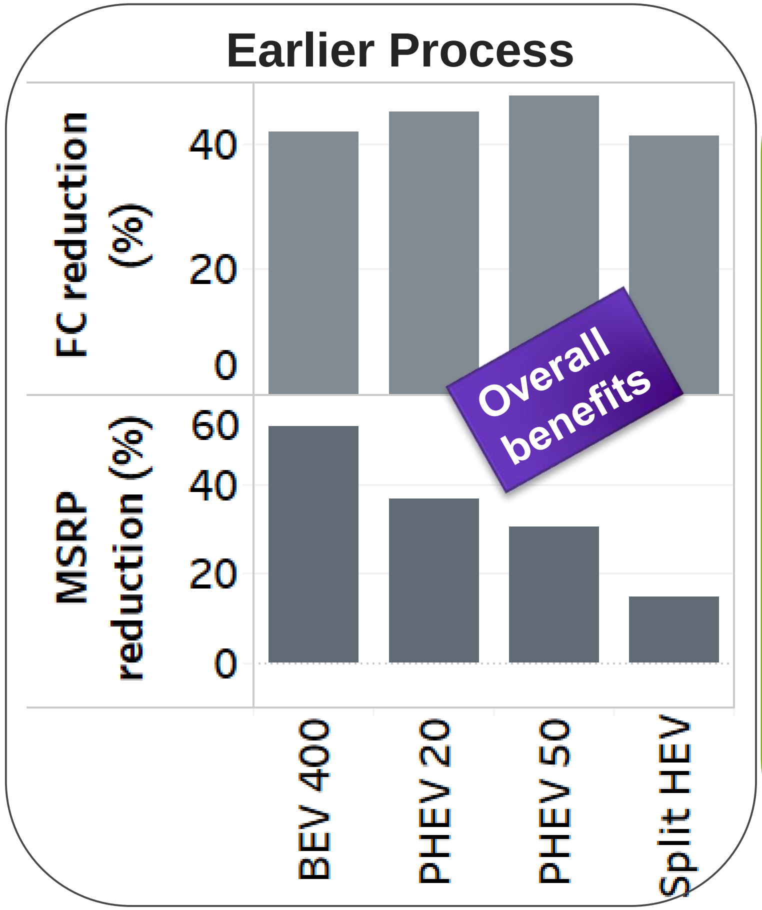
Task 1:
Quantify Individual Technology Contribution

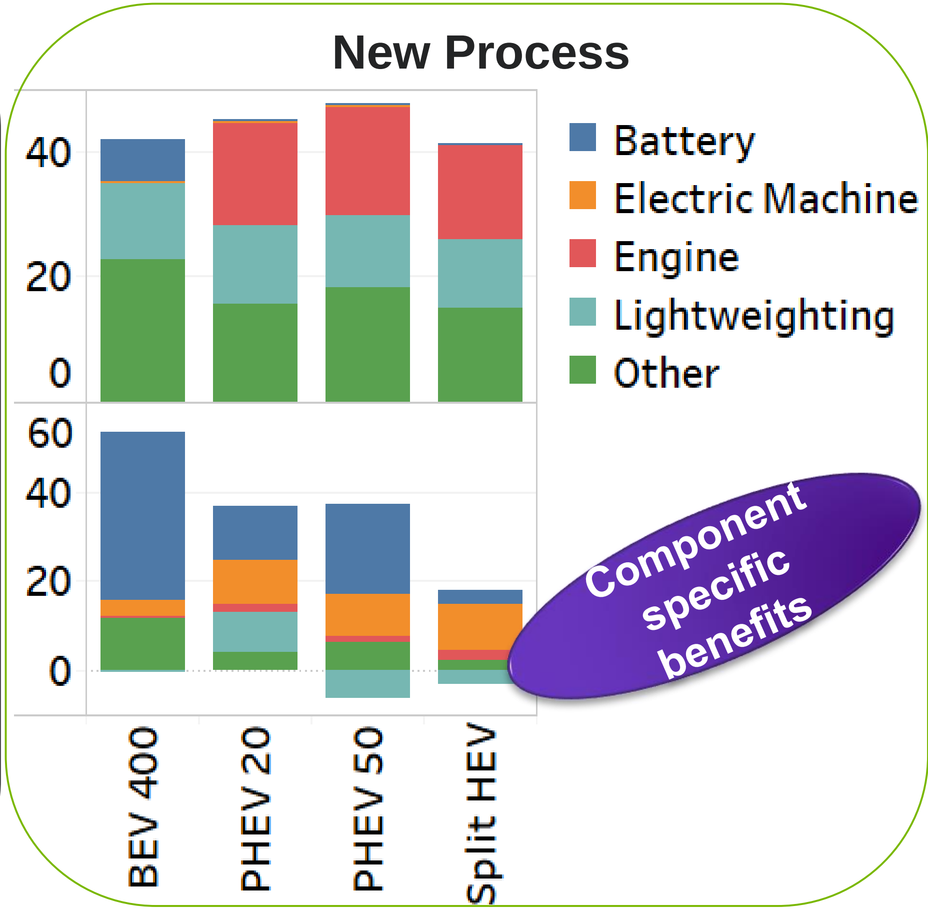
Project Relevance

Quantify Impact of Specific Technologies Funded by Vehicle Technology Office

Technology Forecast

Sample Parameters*	2050
Engine peak efficiency	47%
Glider Light weighting	32%
Battery ($/kWh)	80
(Wh/kg)	320
Motor Cost ($/kW)	4
Aero Drag Reduction	30%
Rolling Resistance Reduction	30%





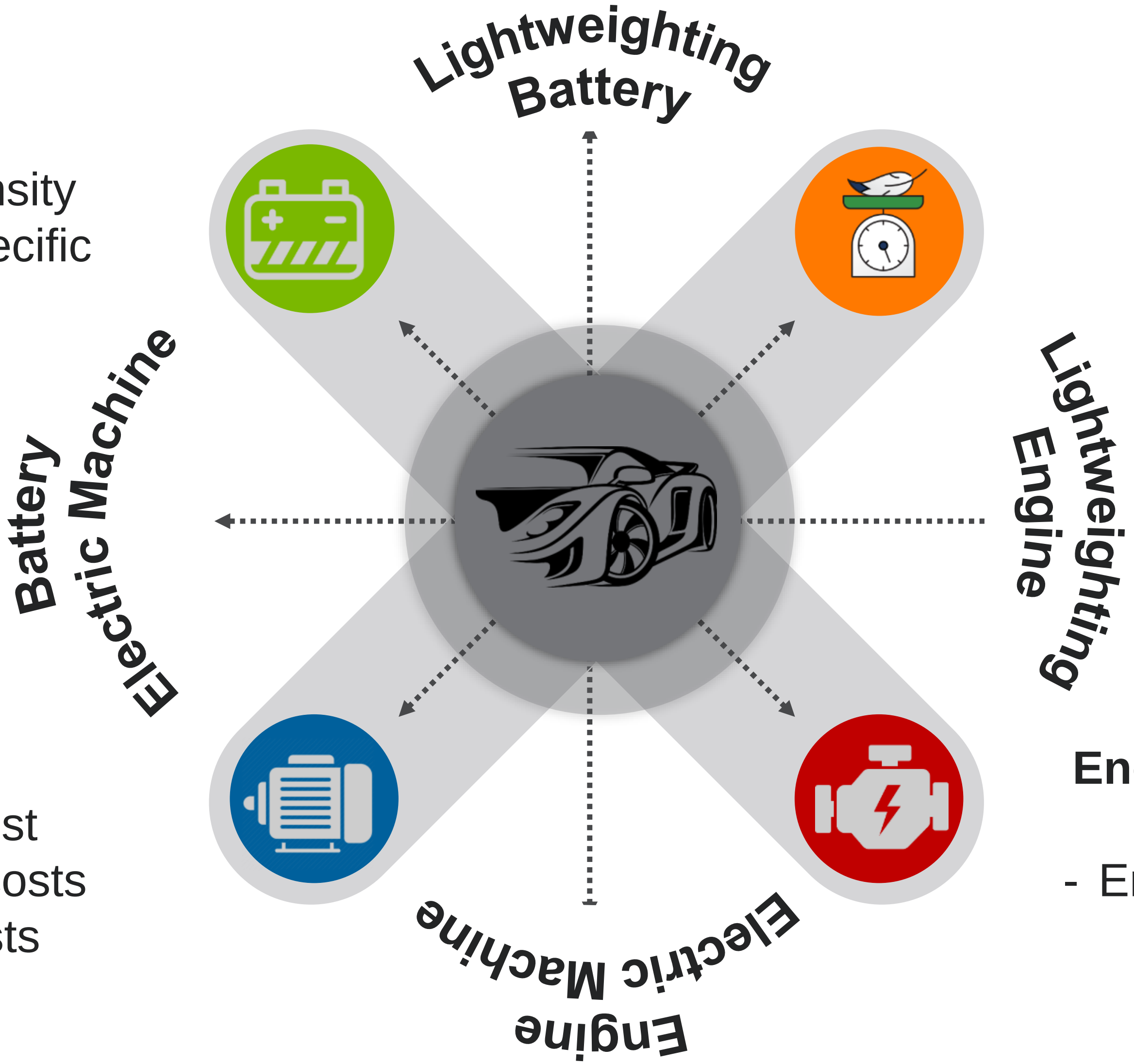
- In previous years, we have estimated the benefit of combined technologies.
- This work expands the analysis to quantify the contributions of individual technologies.

**More details of the parameter changes are provided in backup slides & BaSce report*
https://www.autonomie.net/publications/fuel_economy_report.html

Approach: Simulate All Technology Combinations

Gasoline P/HEV Vehicle Example

Battery
- Energy / Power density
- Useable energy specific cost ($/kWh)



Lightweighting Targets
- % Reduction in glider weight
- Cost of lightweighting ($/kg saved)

Electric Machine
- Electric machine cost
- On-board charger costs
- DC-DC charger costs

Engine Efficiency Targets
- Engine peak efficiency
- Engine part-load efficiency
- Engine technology evolution

Over 500 combinations are evaluated to quantify the contribution of each technology

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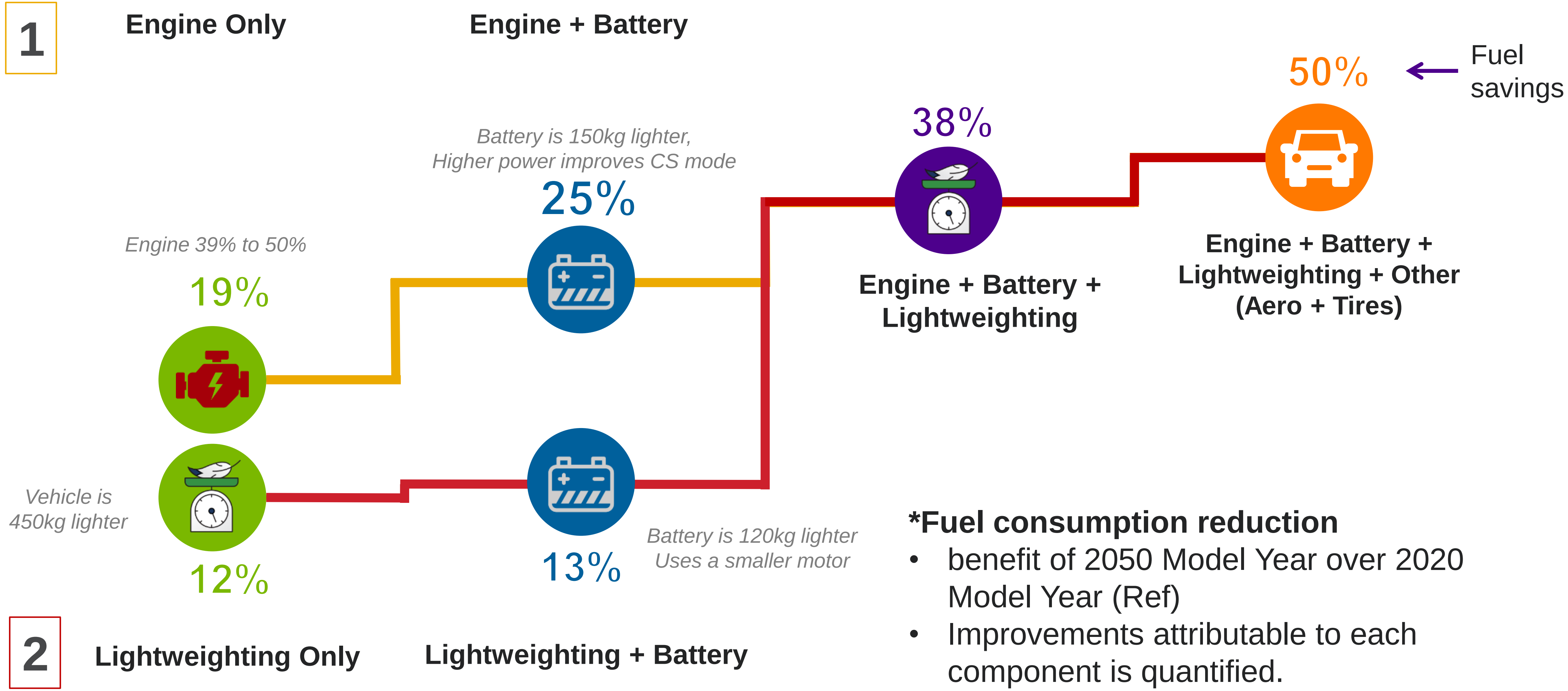
Approach

Individual Technology Benefits* Depend on the Implementation Order (Pathway Selection)

Illustrative example using PHEV50 midsize vehicle



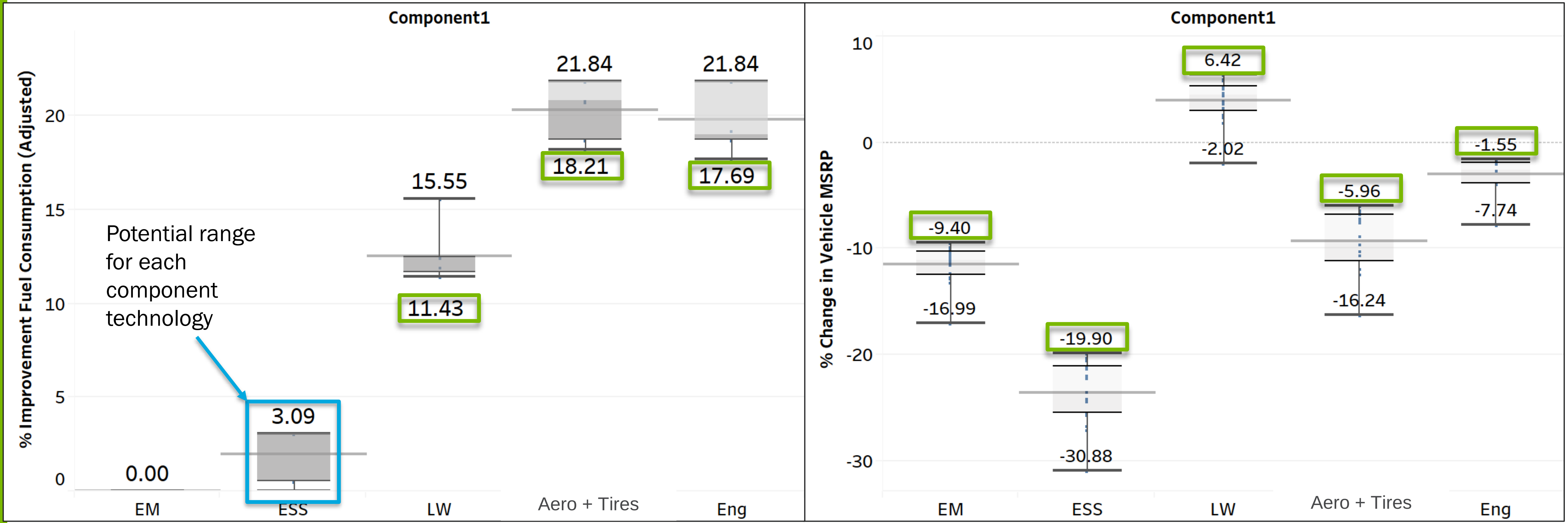
***Fuel consumption reduction**

- benefit of 2050 Model Year over 2020 Model Year (Ref)
- Improvements attributable to each component is quantified.

**Refer backup slides for component improvements assumed for this work*

Range of Individual Component Contributions – PHEV50

The Minimum / Maximum Of Individual Component Contributions Depend On The Order Of Technologies Modeled



Minimum benefit ***from each component*** occur when all technical targets are ***simultaneously*** met

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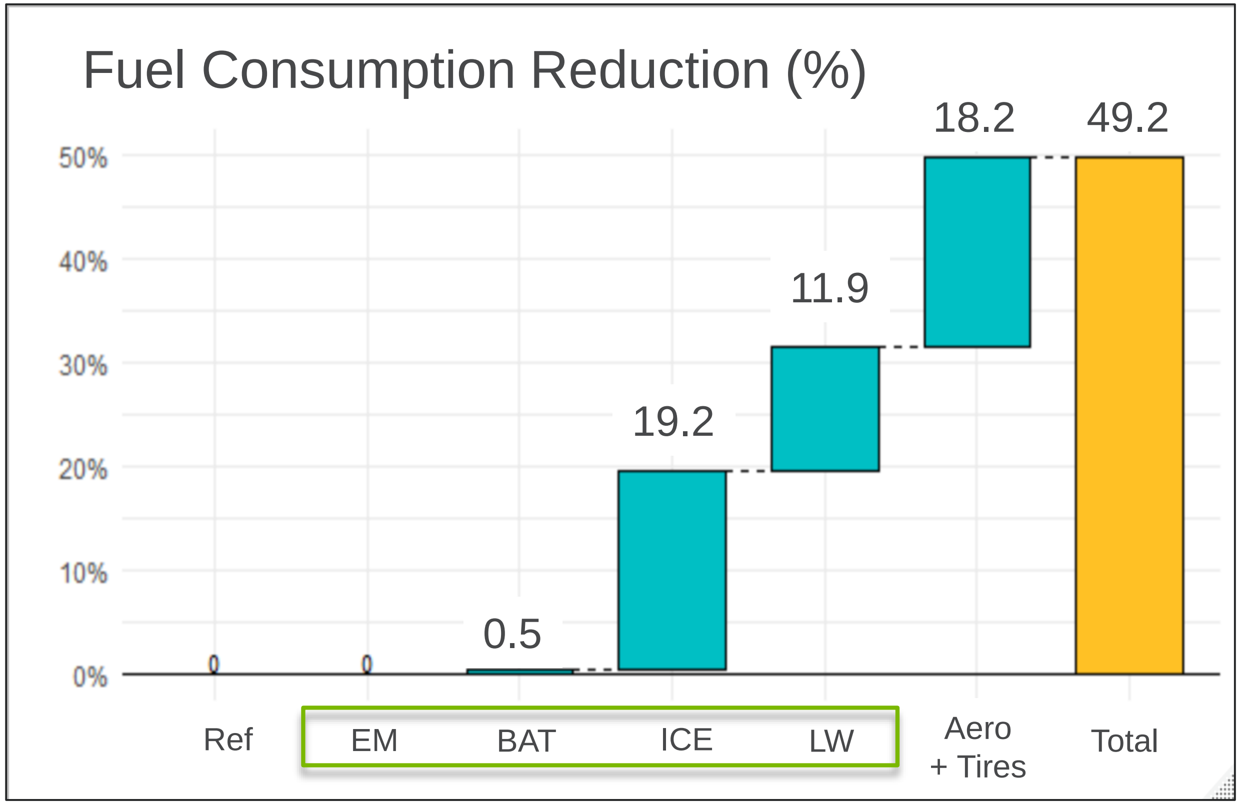
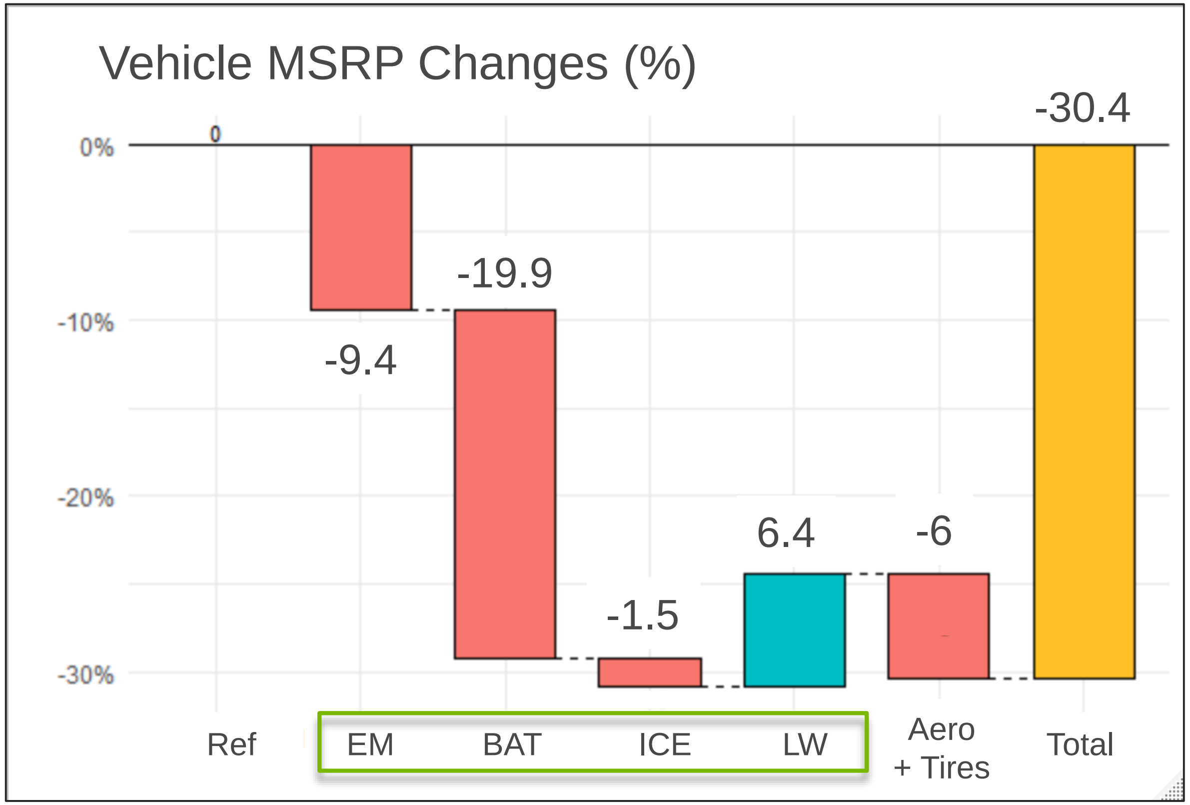
Technical Accomplishments

Individual Component Contributions : PHEV50 Example





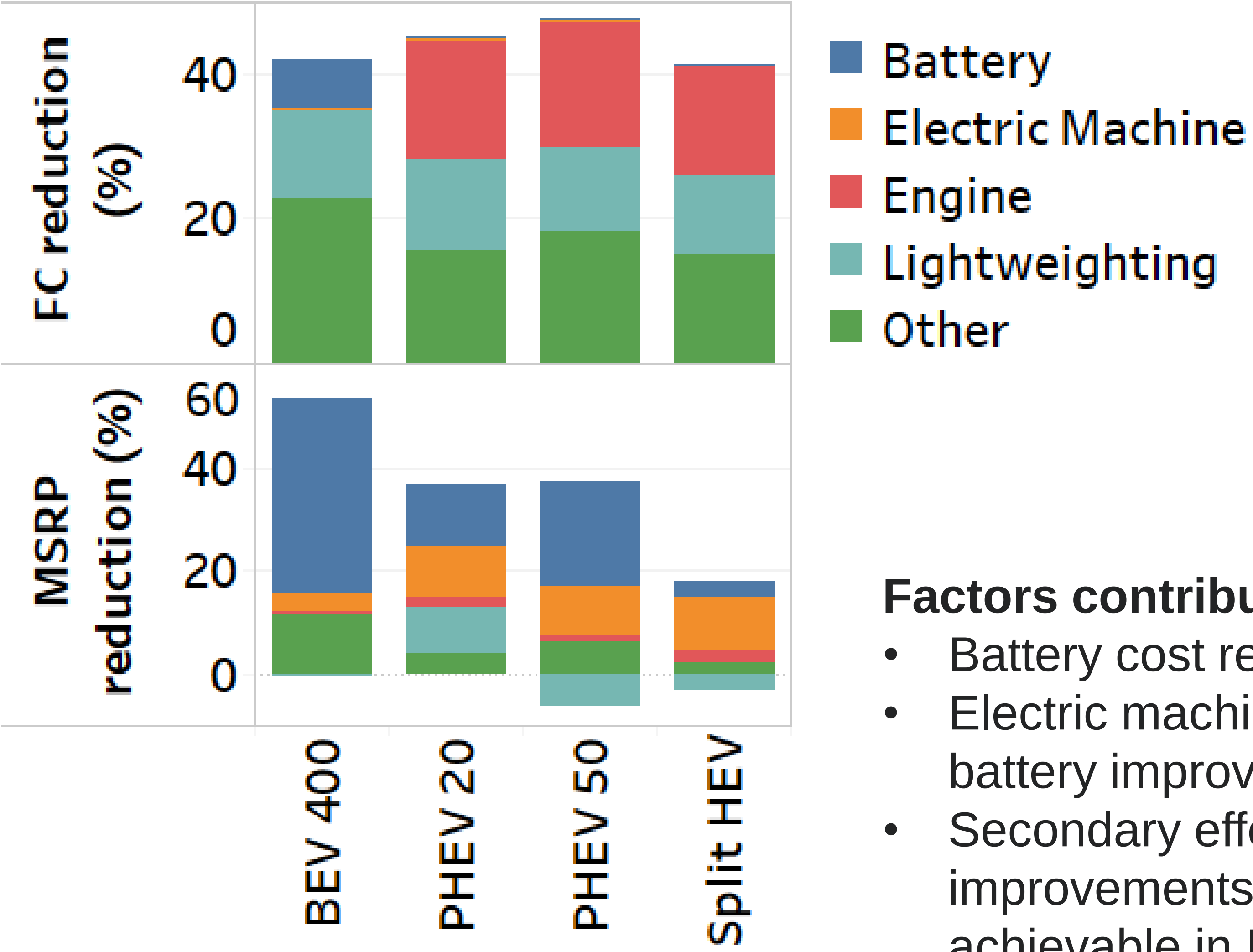
Order of contribution:
ICE > Aero + Tires > LW > BAT

VTO Technical Targets for electric machine (EM), batteries (BAT), engine (ICE) and lightweighting (LW)

Order of contribution:
BAT > EM > ICE > Aero + Tires > LW

Technical Accomplishments

Individual Component Contributions Are Quantified For HEV, PHEV & BEV



Factors contributing to fuel consumption reduction

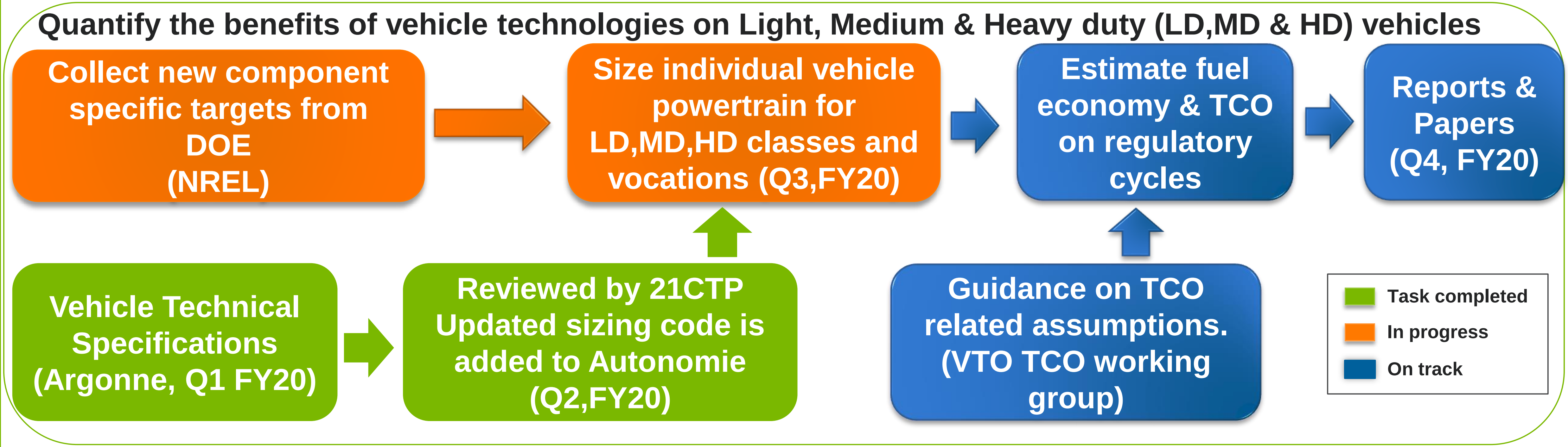
- Nearly 1/3rd of fuel savings in HEV& PHEV will be from better engines.
- Light weighting, Aero & Rolling resistance improvements are important for all vehicles.
- Secondary effects of battery & motor weight reduction is <5%

Factors contributing to MSRP reduction

- Battery cost reduction is very important for BEV & PHEV.
- Electric machine improvements are more important than battery improvements for reducing cost of HEVs
- Secondary effects of aero & rolling resistance improvements exceed 10% of the total cost reduction achievable in BEV

Task 2: Quantify Cumulative Vehicle Technology Benefits

Approach



- **What is new in this year's work ?**
  - Updated technology progress assumptions and targets
  - Updated assumptions on vehicle specifications, performance targets & sizing methods based on industry feedback
  - Uniform assumptions across multiple studies on TCO estimates

- *Results from prior work is published (see slide on 'publications' for details)*

Technical Accomplishments

Increased Number of Truck Models Defined in AMBER/Autonomie

Class	Vocation
2b	Small Van
3	Enclosed Van
3	School Bus
3	Service, Utility Truck
4	Walk In, Step Van
4	Light HD
5	Utility, Tow Truck
6	Construction, Dump Truck
6	Medium HD
7	School Bus
7	DayCab (3)
7	Medium HD
8	Construction, Dump Truck
8	Drayage
8	Refuse, Cab over type
8	Tractor Trailer
8	40' Transit Bus
8	Heavy HD
8	DayCab (3)
8	Sleeper (3)

- Over 20 class/vocation combinations are currently available, covering a majority of trucks in US (refer to backup slides for details)
  - **59%** of the trucks by numbers
  - **82%** of the miles driven by trucks
  - **85%** of the fuel used by trucks

- Various market penetration tools use subsets of this work for their analysis
- Detailed energy consumption, cost and TCO analysis is performed on a selected subgroup of class-vocation combinations.
- Six powertrains are currently available class/vocation combination.
  - Electrified powertrains are modelled as direct drive architectures where it can meet sizing requirements.
- Post-processing tools and results format for data sharing are consistent with ones previously developed for light duty vehicles

Technical Accomplishments

Included Additional Sizing Criteria and Specific Test Conditions

- **Sizing Updates**
  - Launch at grade
  - Highway gradeability
  - Performance at max GVWR for each class
  - Energy consumption tests with vocation specific cargo loads
  - Test durations are added for electric powertrains
- Vehicle specifications & sizing logic details are published as supporting documents of 2019 VTO Benefit Analysis report

- Performance tests @ max GVWR
  - Cruising speed
  - 1% Grade @ 65mph
  - 6% Grade climb for 11 miles at 30mph
  - Launch @ 15% grade
  - Acceleration & Passing
    - 0-30mph & 0-60mph
  - All Electric/Driving Range

- Fuel economy tests @ regular load
  - EPA regulatory cycles
  - Real World Cycles (Livewire, FleetDNA, CERC)
- TCO/LCOD
  - Component Cost:
    - DOE targets
- Fuel Costs
  - AEO 2019

Technical Accomplishments

Component specifications determined to meet or exceed the vehicle requirements.

Preliminary results for two powertrains

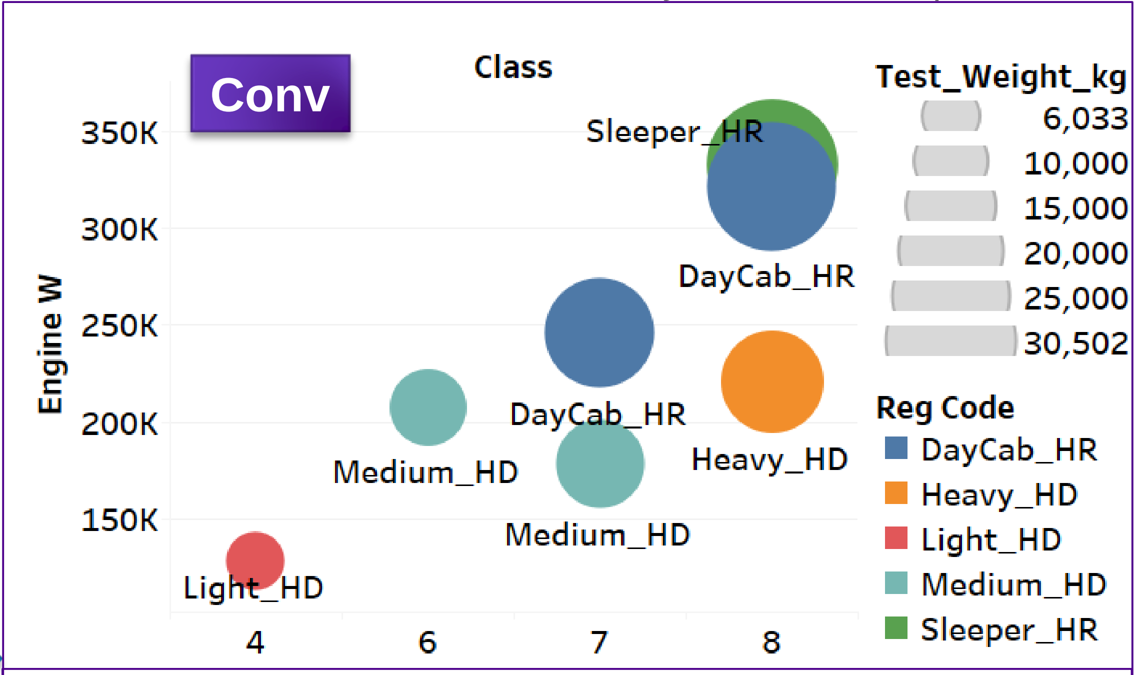
Vehicle requirements*	Class 8 Line Haul
Speed at 6% grade	> 30 mph
Grade at 65 mph	1.25%
0-60 mph acceleration	< 80 sec
0-30 mph acceleration	20 sec
Startability (creep continuously (<1mph) for 2 minutes)	15%
Daily driving	500 miles

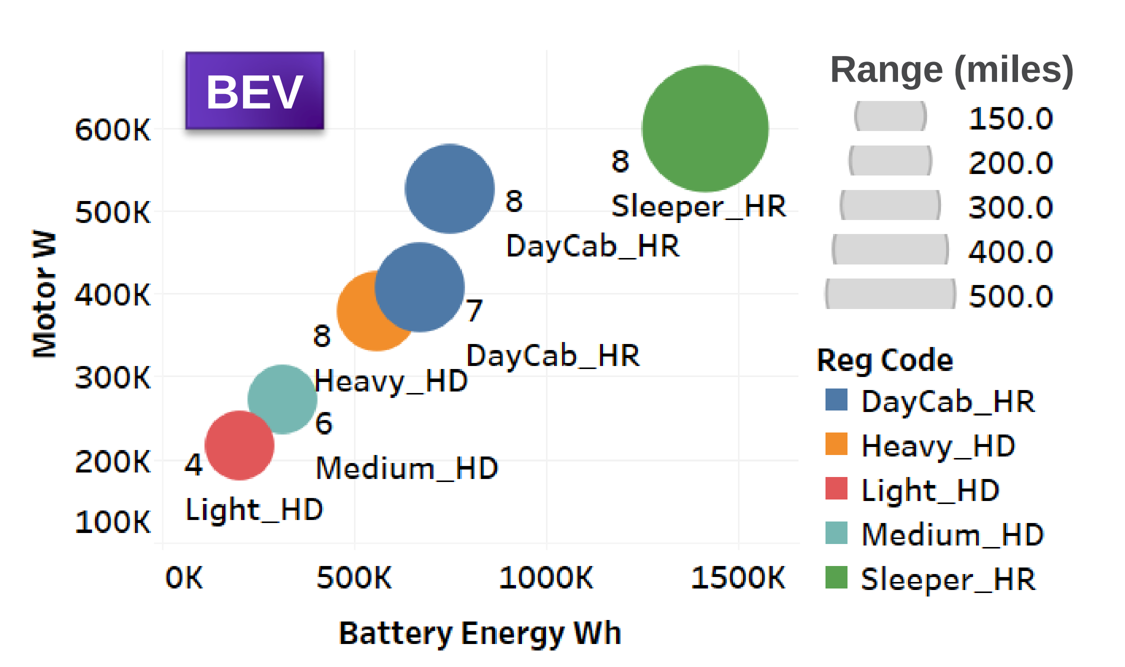
** Performance requirements at GCWV of 80,000 lbs or 82,000 lbs where feasible*

Refer of the backup slides for full list of requirements

Representative vehicle assumptions

Sizing Process





Detailed results for all vehicles on 6 powertrains will be published by end of FY20 Q4.

Next Steps: Estimate fuel consumption & TCO

With assumptions on how various technologies will progress in future

Vehicle Requirements

Component Sizing

Technology Progress Assumptions

Completed

AUTONOMIE

Vehicle simulation
LD,MD,HD vehicles
Time frame: 2020 → 2050
6 powertrains
EPA regulatory cycles

Component Cost

Vehicle Cost

Fuel/Energy Consumption

TCO

Analysis, Reports & Publications

In progress

Comments from Previous Reviews

Reviewer Comments	Answers
A mature process like this should be able to reduce the time & effort needed for the analysis	• Continue to minimize manual intervention to build models and set up large scale simulations • Occasional rework is necessitated because of issues identified at QAQC stage. However such cases are very few • MD&HD process is still being improved with feedback from many stakeholders
One reviewer suggested more collaboration with OEMs and academic agencies	• This years' work incorporates a lot of feedback from 21CTP & learnings from CERC project • Regularly provide insights to the target setting process at U.S. DRIVE, and other U.S. CAR partnerships • Powertrain sizing process as well as vehicle specifications have been updated based on collaborations
More user friendly interface for Autonomie was suggested by a reviewer	• The development of a new user friendly interface is being developed with AMBER (EEMS013). • Powertrain sizing logics have already been added to AMBER/Autonomie GUI. The development of large scale simulation specific GUI is in process

Remaining Challenges and Barriers

- Evaluating component specific improvements increases the overall number of simulations by a few orders of magnitude.
  - Millions of simulations are carried out using HPC

  => Need to automate the process from beginning to end
- Need to include additional powertrain and component technologies as they become available in the market

  => A single new technology requires 10,000+ simulations if the combination with all other technologies are being considered
- Integrate better cost estimations (e.g., component, vehicle, operation, etc.)
- Manage stakeholders diverse demands

Collaborations

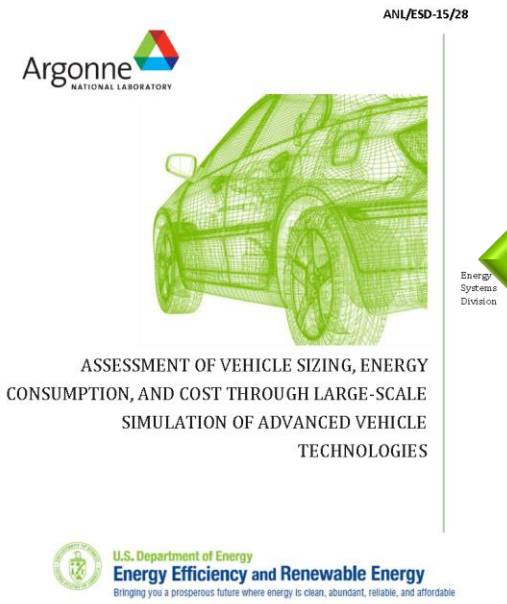
Inputs

National Labs.

Autonomie users

…

Analysis & Reports



Stakeholders

- VTO and FCTO Benefits
- SPIA (ATB)
- U.S. DRIVE C2G (Cradle to Grave) Working group
- GHG (GREET)
- Market penetration tools (MA3T, LAVE-Trans, LVCFlex, ParaChoice, ADOPT)
- DOE Advanced Tech Modeling runs with NEMS
- U.S. EPA
- Multiple research organizations (IEA, AVERE…)
- …

Future Research

- Electrified powertrains are in an early stage for trucks. Setting the right technology targets will accelerate the introduction of efficient technologies. This work will guide the target setting activities across various DOE offices.
  - Vehicle models have to be periodically updated to model new technologies in production as well as predicted technology evolution
- Evaluate economic feasibility of technical solutions require integration of TCO calculations and parameters from VTO Analysis Task Force
- Disseminate assumptions, results and models[1]
  - Provide the database of vehicle characteristics along with the related assumptions for wider research use.
  - Share vehicles through Autonomie (full code access) and through file shared system (compiled models)

(1) https://www.autonomie.net/publications/fuel_economy_report.html

Any proposed future work is subject to change based on funding levels

Summary

- This work aims to quantify the fuel saving and TCO benefits of VTO funded technologies.
- Inputs from DOE technical managers, national labs and industry partners are continuously collected to update the results.
- Contributions of individual VTO technologies (e.g. engine, light weighting, battery, electric machines) on energy consumption and cost have been quantified for a midsize car across multiple powertrain configurations and timeframes.
- MD & HD vehicle specifications & sizing requirements have been updated with new industry inputs.
- Component sizing results have been determined for several class/vocation/powertrain combinations.
  - Work is in progress to quantify the fuel saving potential of VTO funded technologies & economic feasibility of electrified powertrains
- Detailed analysis and report will be completed by FY20 Q4.
  - Expertise & insights gained from this work will be used to support multiple projects including technology target setting activities, market penetration & life cycle analysis
- Models, initialization assumptions and processes to replicate the results will be shared through Autonomie for wider use by research agencies.

REVIEWER ONLY SLIDES

Publications

Reports submitted to DOE

- ANL-19/58, “Vehicle Technologies and Fuel Cell Technologies Office Research and Development Programs: Prospective Benefits Assessment for Medium and Heavy Duty Vehicles”,
  T.Stephens, R.Vijayagopal, M.Dwyer, A.Birky, A.Rousseau

- ANL/ESD-19/8, “Fuel Economy and Cost Estimates for Medium-and Heavy-Duty Trucks”,
  R. Vijayagopal, D.Nieto Prada, A. Rousseau

- ANL/ESD-19/10 “A Large-Scale Vehicle Simulation Study To Quantify Benefits & Analysis of U.S. Department of Energy VTO & FCTO R&D Goals”
  E.Islam, A.Moawad, R.Vijayagopal, A. Rousseau

Conferences & Journals

- Vijayagopal, R. et al. Benefits of Electrified Powertrains in Medium- and Heavy-Duty Vehicles. *World Electr. Veh. J.* 2020, *11*, 12.
- E.Islam et al.,”20PFL-0561 Detailed Analysis of U.S. Department of Energy Engine Targets Compared To Existing Engine Technologies” SAE WCX 2020
- R.Vijayagopal et al, “Electric Truck Economic Feasibility Analysis”, accepted at EVS 33, 2020

BACKUP SLIDES

Component Specific Assumptions:
Lab Year 2015 – VTO Benefits Analysis

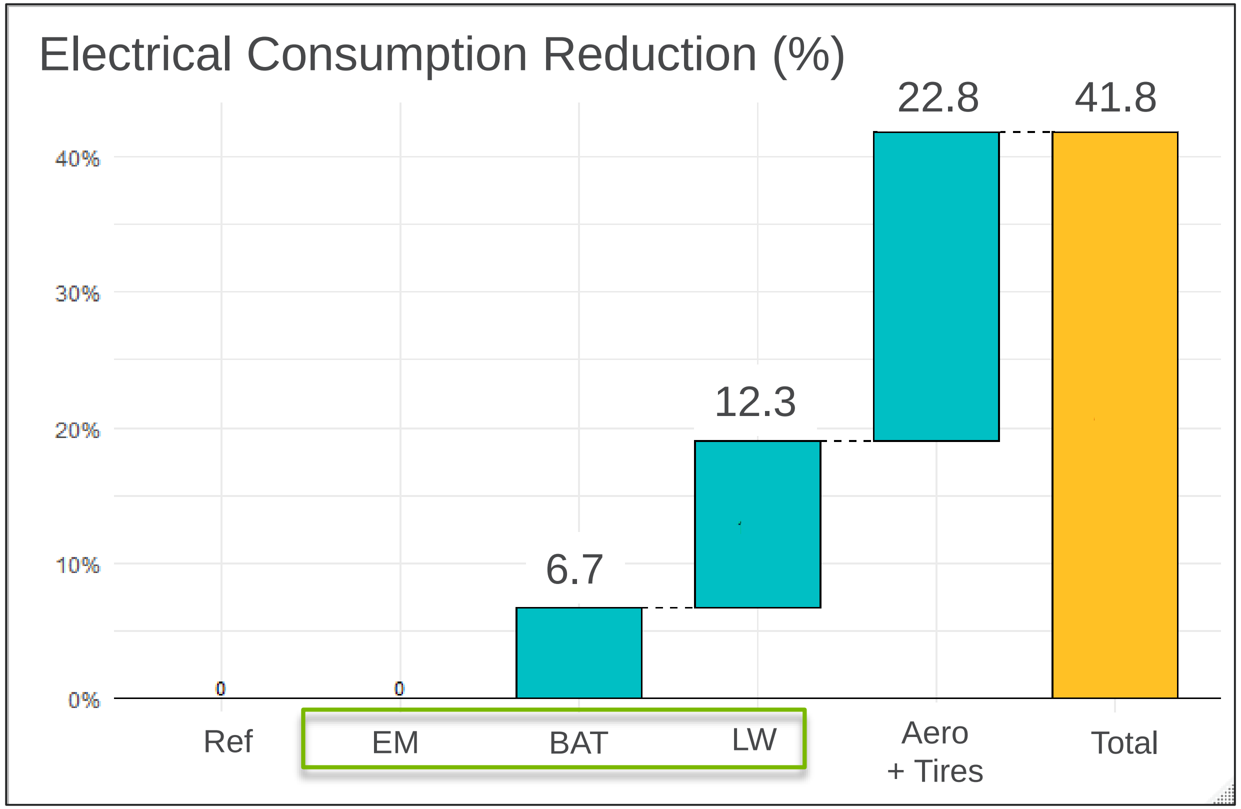
Lightweighting / Aero and Roll ("Other")	Battery	Electric Machine	Engine
Lightweighting: 0% (Glider)	Specific Power (W/kg): 2750	Boost Converter Cost ($/kW): 8	Peak Efficiency (Gasoline): 36%
Aerodynamic Reduction: 0%	Usable Energy Density (Wh/kg) – PHEV: 70	High Voltage System Cost ($/kW): 17	Peak Efficiency (Gas. Turbo): 36%
Rolling Resistance Reduction: 0%	Usable Energy Density (Wh/kg) – BEV: 170	DC/DC Buck Converter Cost ($/kW): 65	Peak Efficiency (Diesel): 42%
	Specific Power Cost ($/W): 20	Peak efficiency: 98%	Peak Efficiency (HEV, Atkinson): 39%
	Usable Energy Cost ($/kWh) – PHEV: 500		
	Usable Energy Cost ($/kWh) – BEV: 220		

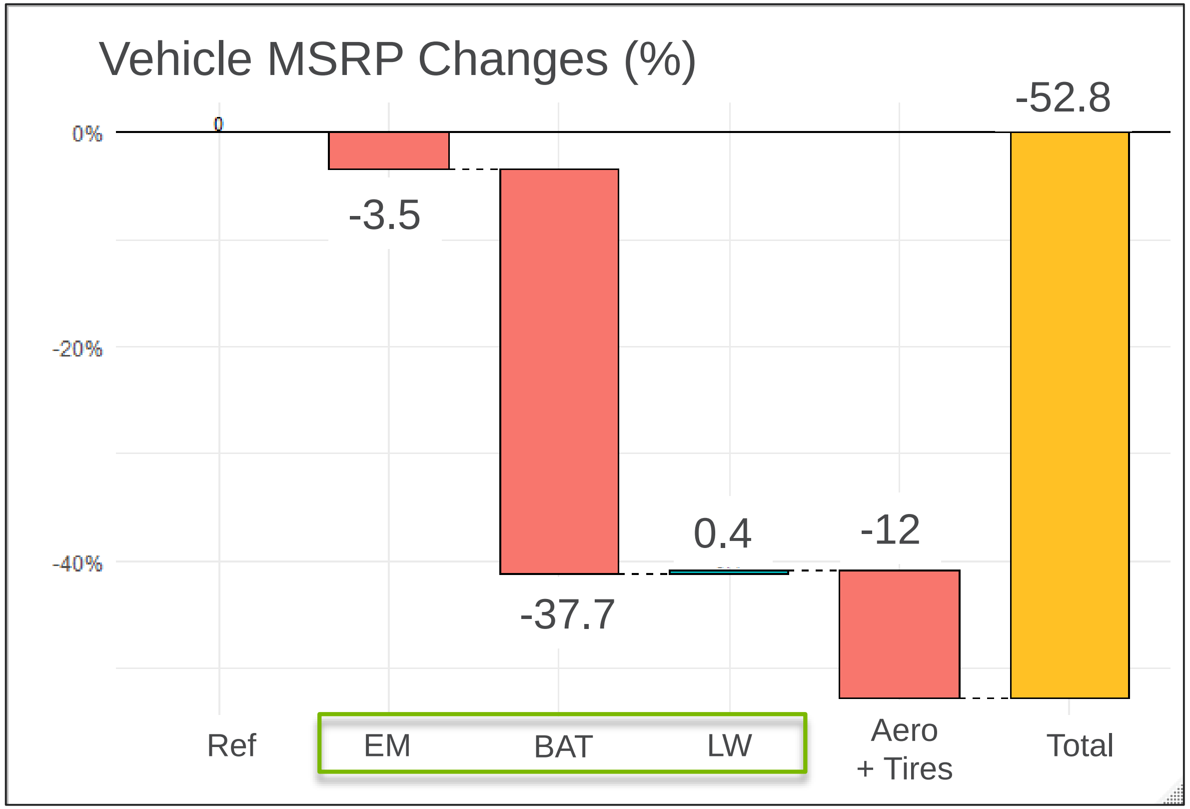
Component Specific Assumptions: Lab Year 2045 – VTO Benefits Analysis

Lightweighting / Aero and Roll (“Other”)	Battery	Electric Machine	Engine
Lightweighting: 32% (Glider)	Specific Power (W/kg): 6000	Boost Converter Cost ($/kW): 2	Peak Efficiency (Gasoline): 47%
Cost of lightweighting ($/kg): 9.00	Usable Energy Density (Wh/kg) – PHEV: 170	High Voltage System Cost ($/kW): 4	Peak Efficiency (Gas. Turbo): 46%
Aerodynamic Reduction: 30%	Usable Energy Density (Wh/kg) – BEV: 320	DC/DC Buck Converter Cost ($/kW): 18	Peak Efficiency (Diesel): 52%
Rolling Resistance Reduction: 30%	Specific Power Cost ($/W): 13	Peak efficiency: 98%	Peak Efficiency (HEV, Atkinson): 50%
	Usable Energy Cost ($/kWh) – PHEV: 120		
	Usable Energy Cost ($/kWh) – BEV: 80		

Technical Accomplishments

BEV 400 miles Individual Component Contributions





Order of contribution:
Aero + Tires > LW > BAT

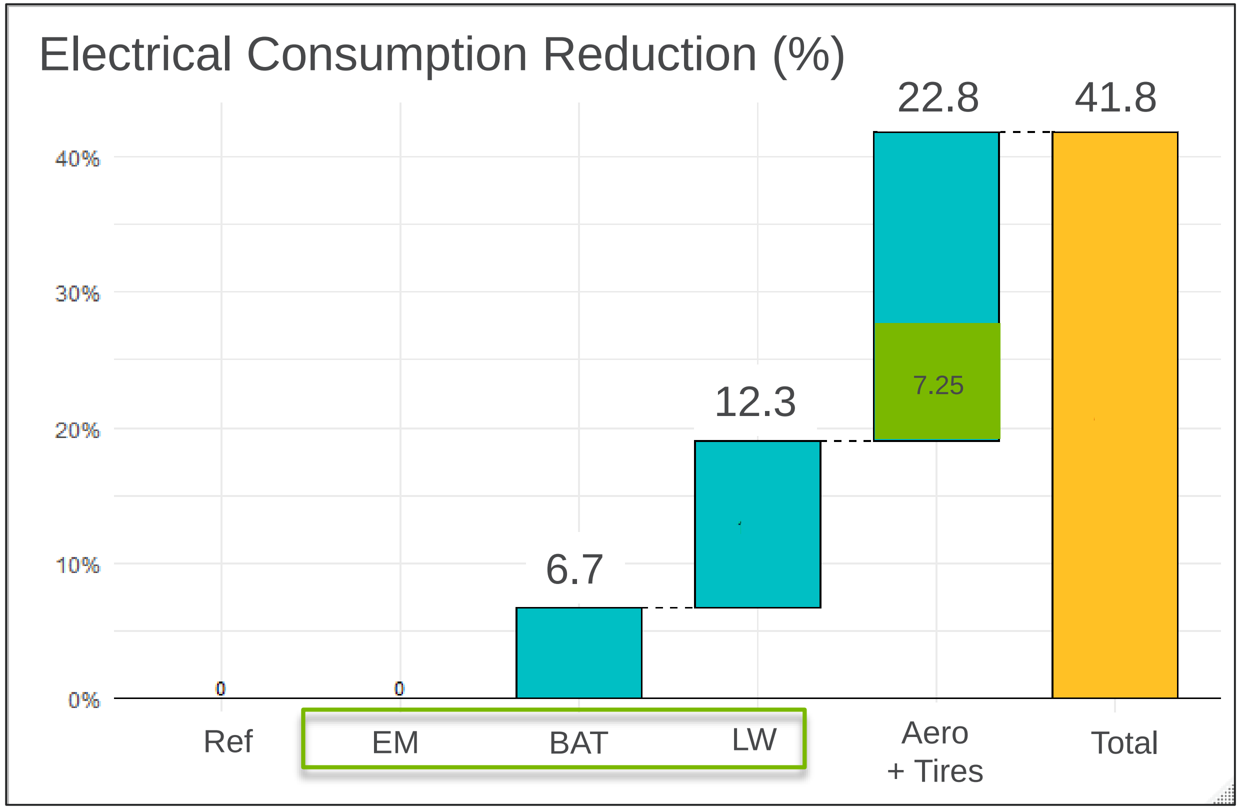
VTO Technical Targets for electric machine (EM), batteries (BAT), and light weighting (LW)

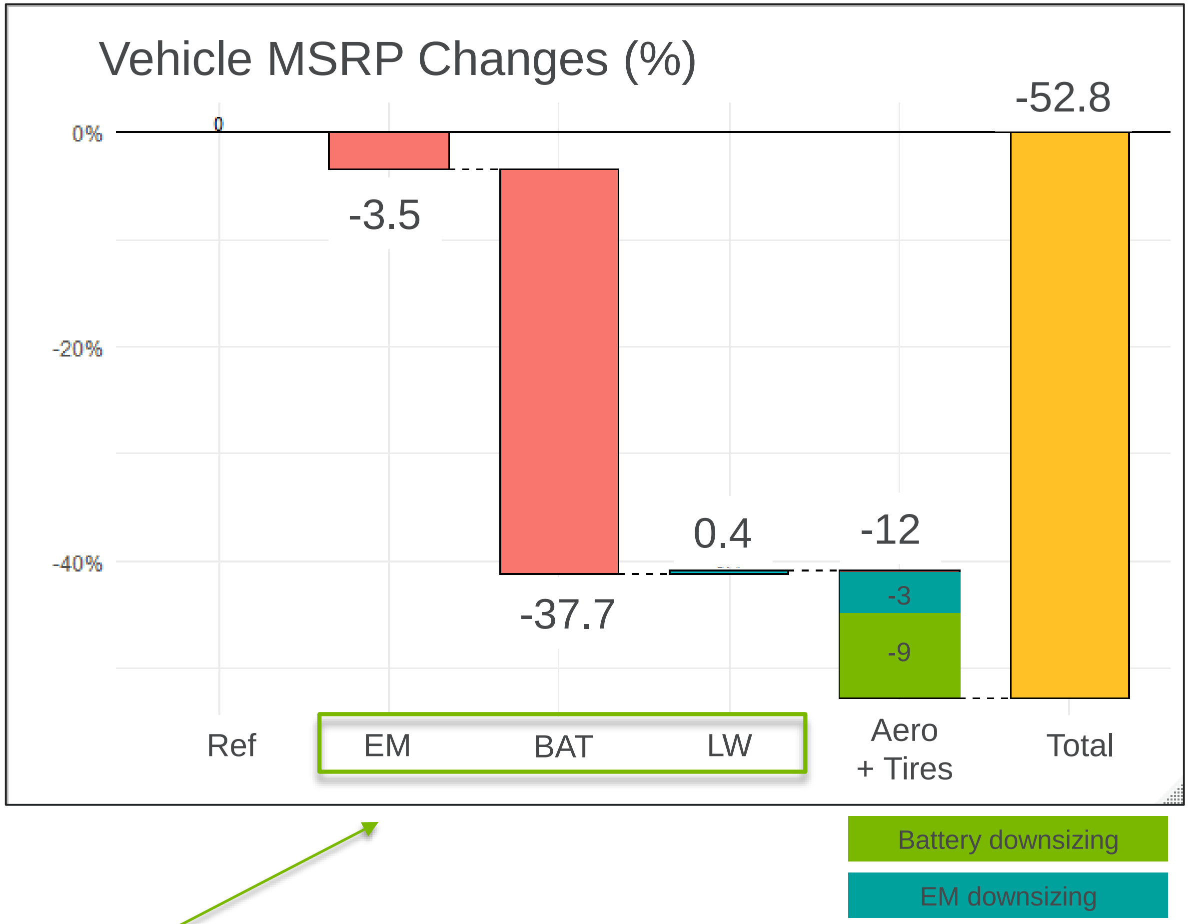
Order of contribution:
BAT > EM > Aero + Tires > LW

Refer backup slides for details

Technical Accomplishments

BEV 400 miles Individual Component Contributions





VTO Technical Targets for electric machine (EM), batteries (BAT), and light weighting (LW)

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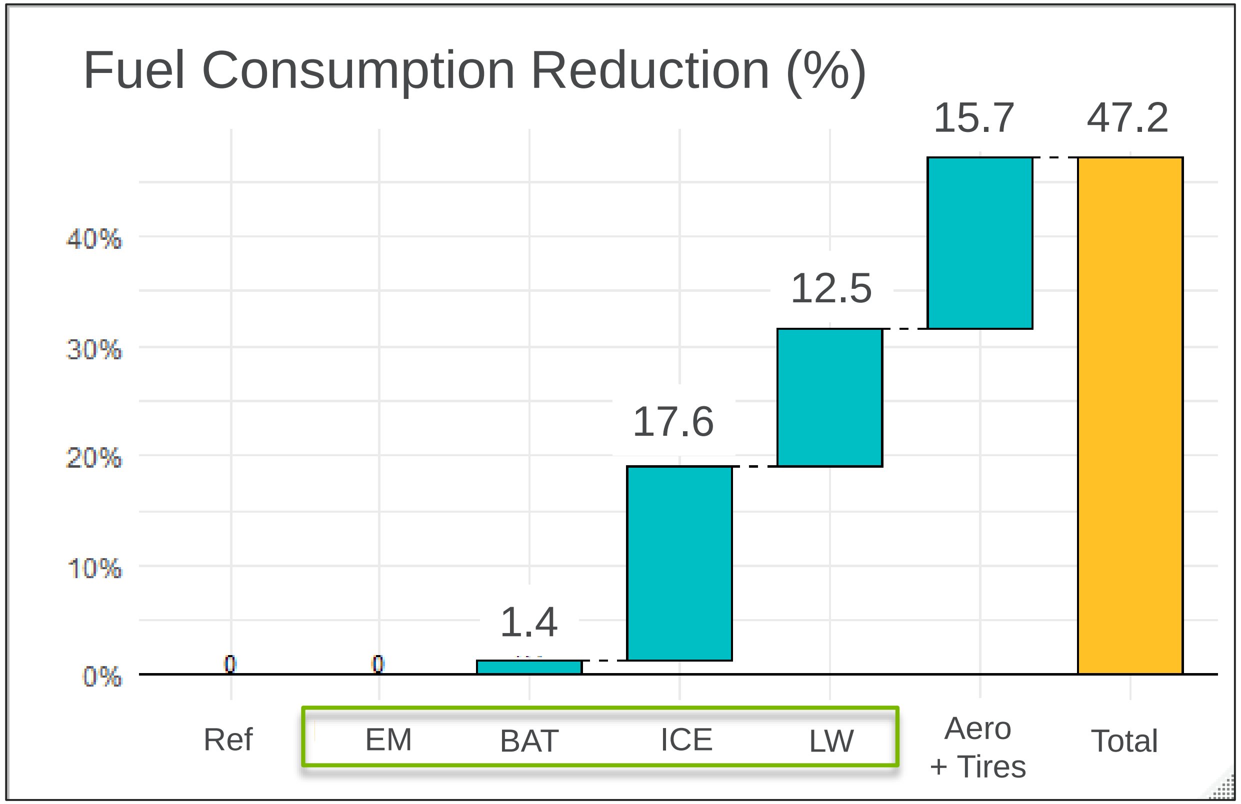
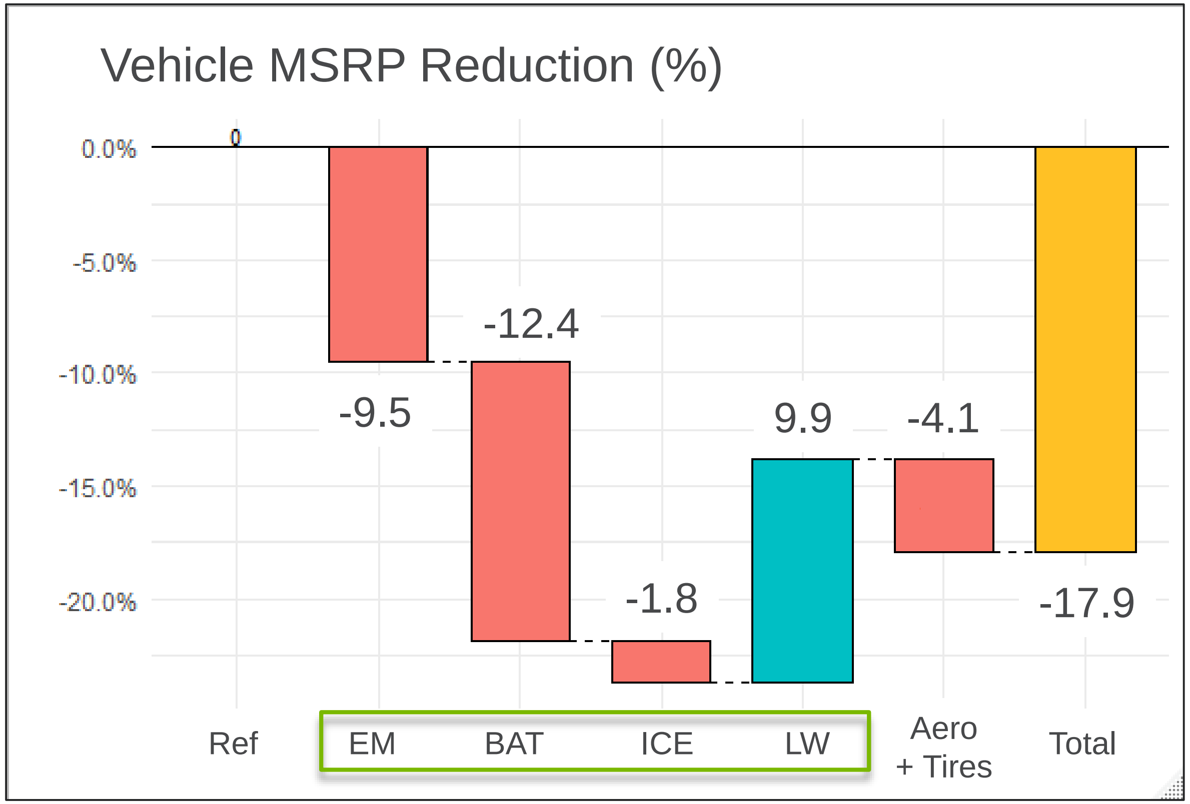
Refer backup slides for details

Technical Accomplishments

PHEV20 Individual Component Contributions

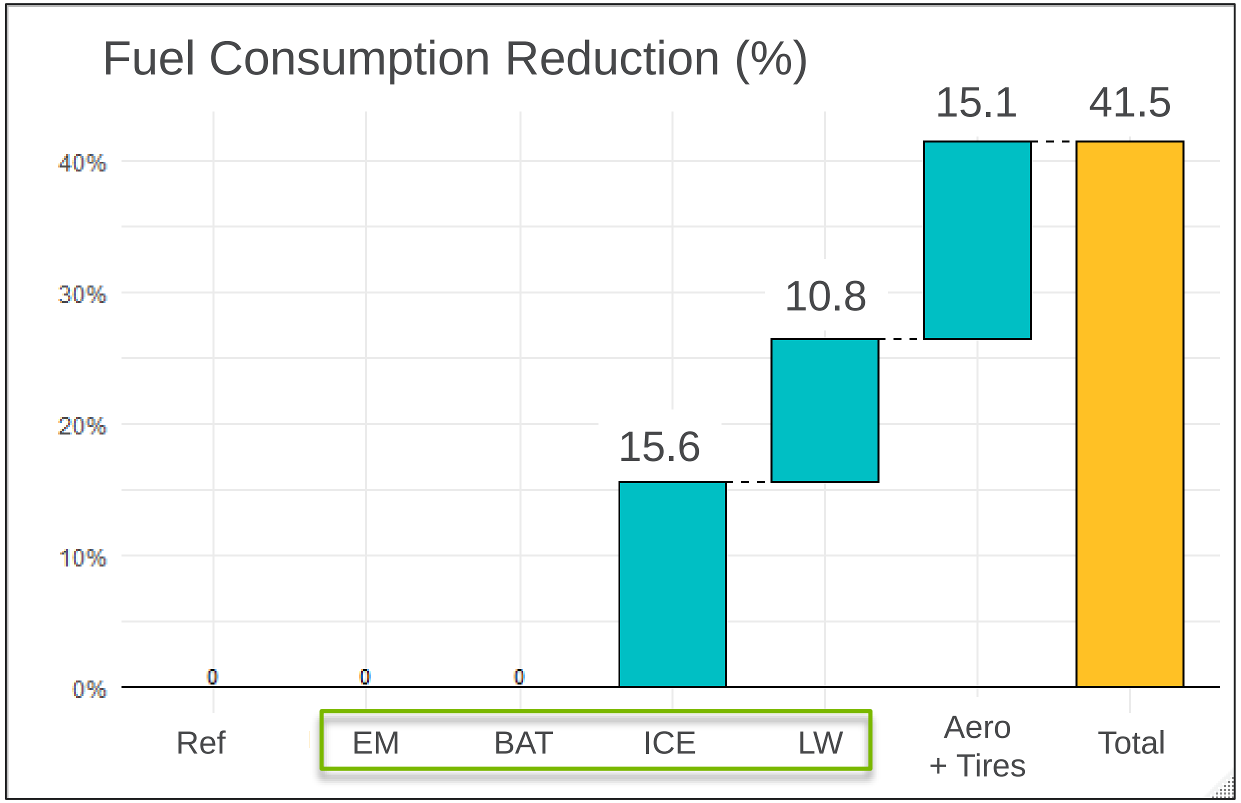


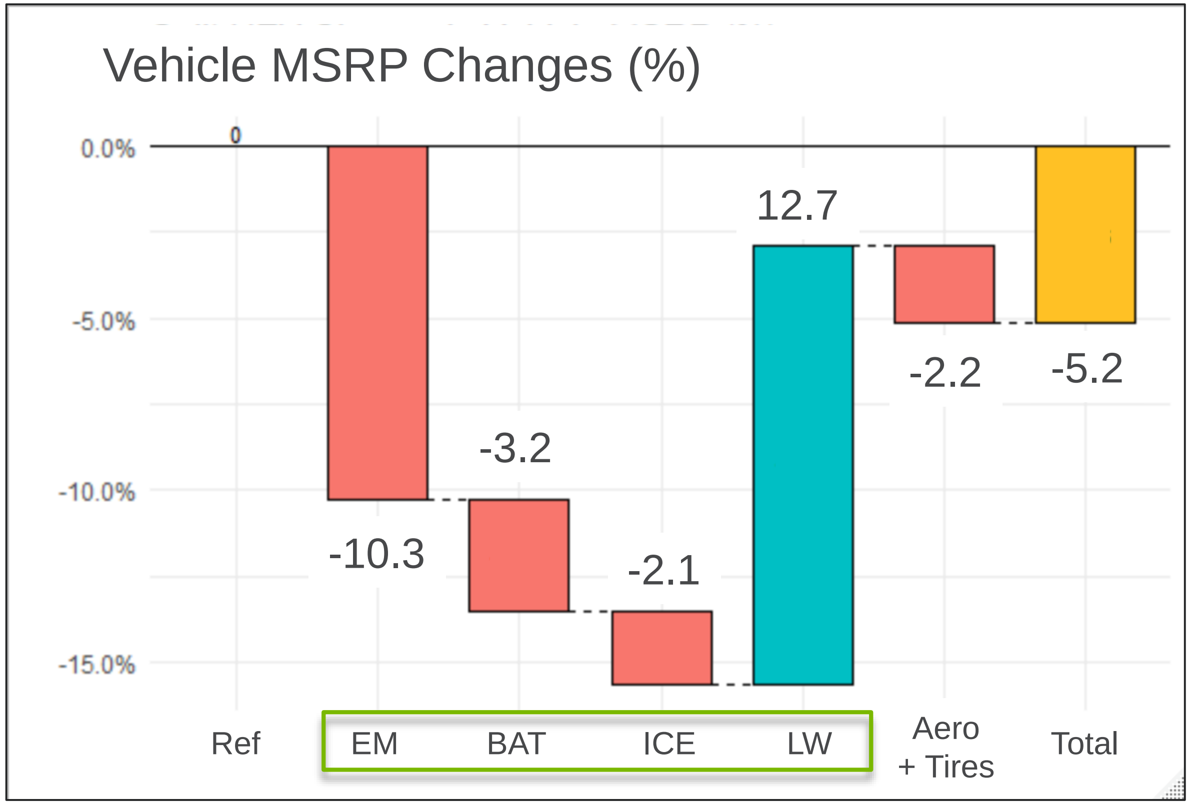


VTO Technical Targets for electric machine (EM), batteries (BAT), engine (ICE) and light weighting (LW)

Technical Accomplishments

Split HEV Individual Component Contributions





Order of contribution:
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VTO Technical Targets for electric machine (EM), batteries (BAT), engine (ICE) and light weighting (LW)

Order of contribution:
EM > BAT > Aero + Tires > ICE > LW

Refer backup slides for details

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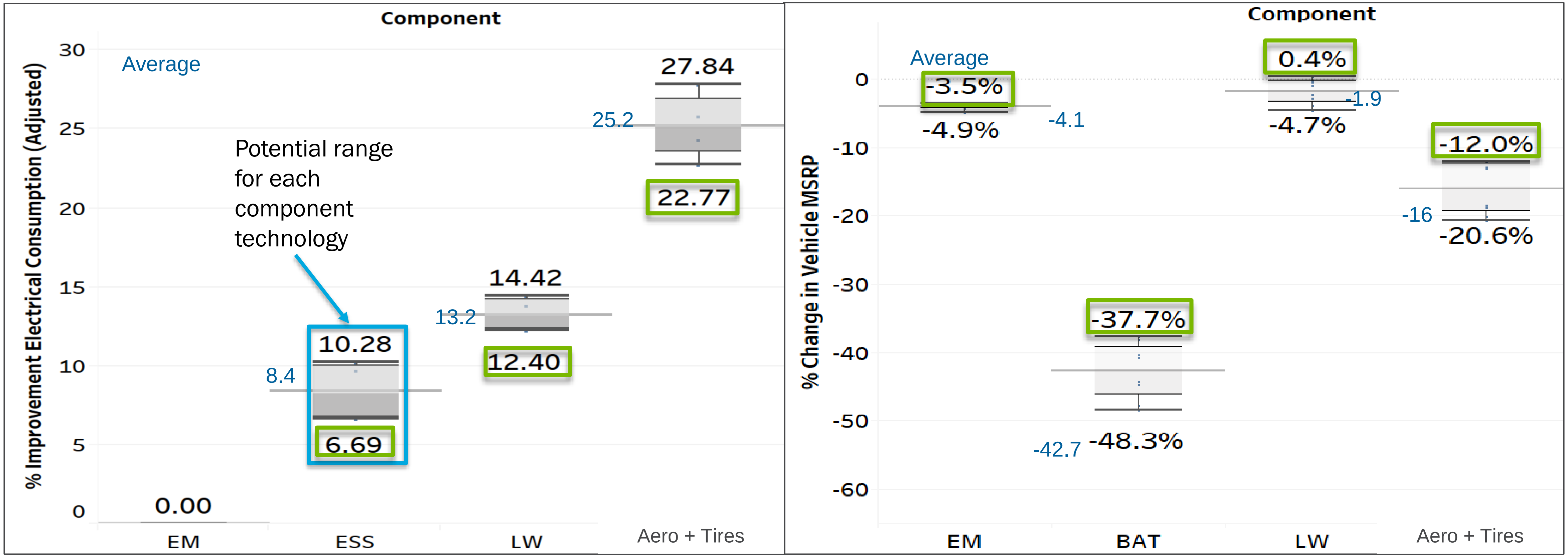
Technical Accomplishments

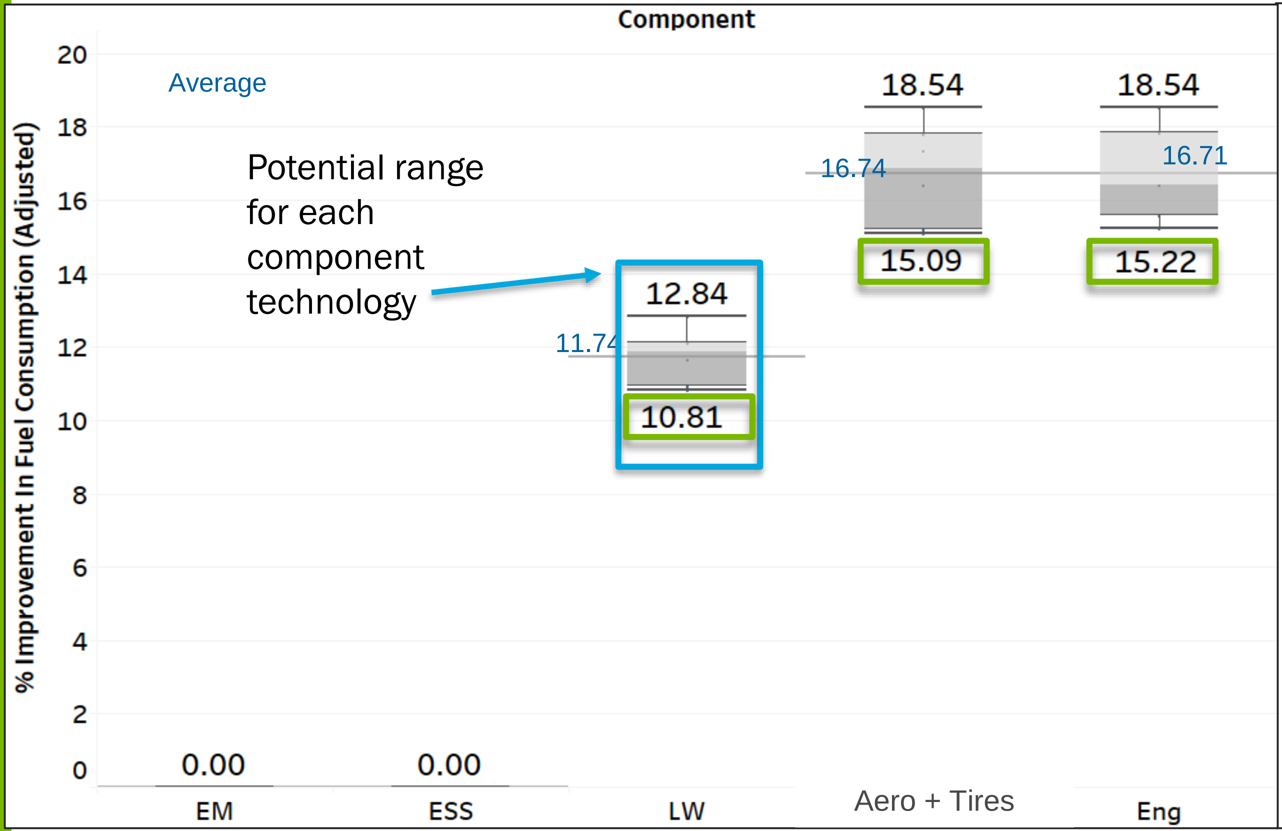
BEV 400 miles Individual Component Contributions

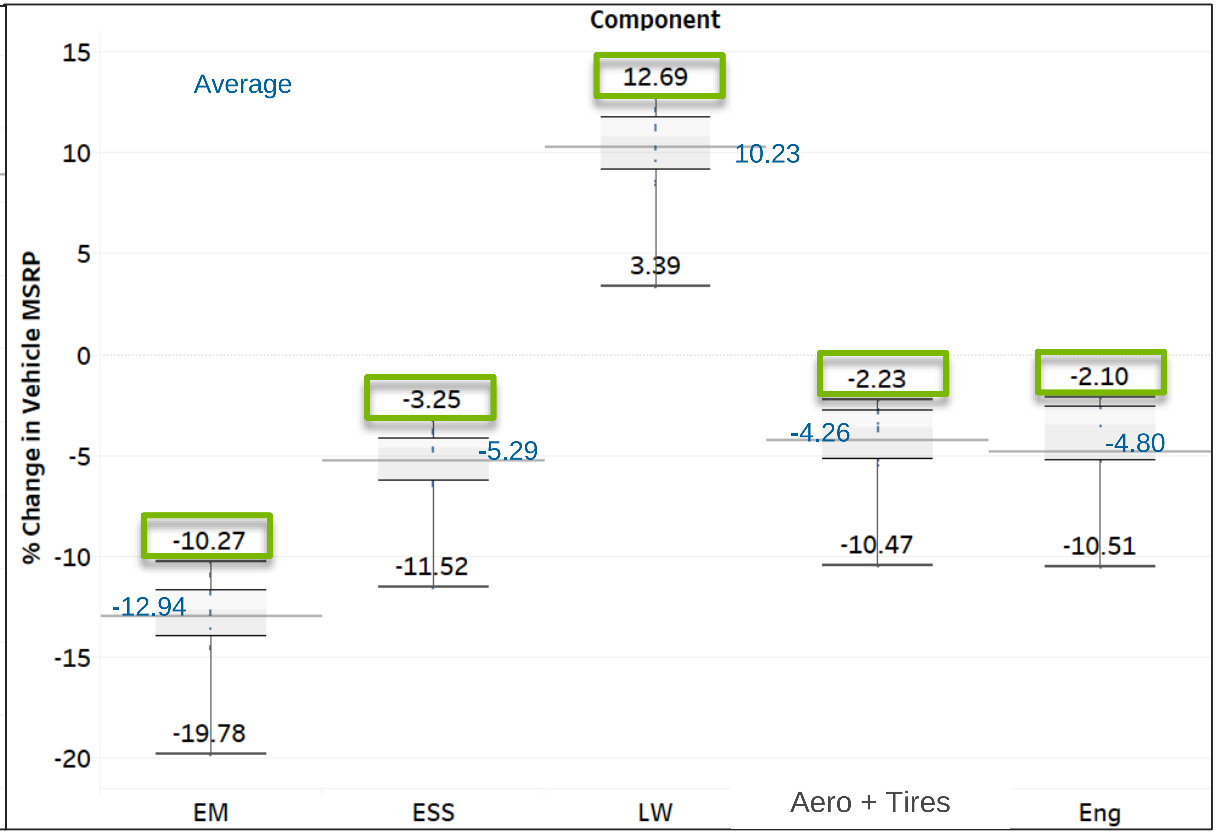


Minimum benefit occur when all technical targets are *simultaneously* met

Range of Individual Component Contributions – Split HEV

The Minimum / Maximum Of Individual Component Contributions Depend On The Order Of Technologies Modeled





Minimum benefit occur when all technical targets are ***simultaneously*** met

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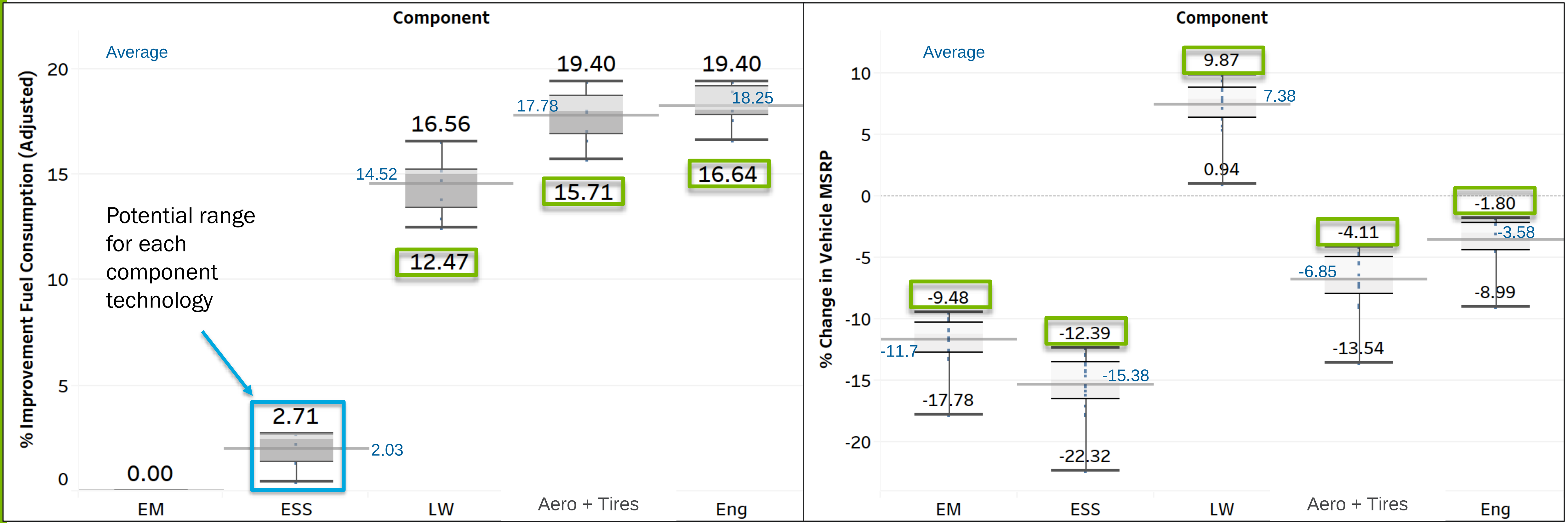
Range of Individual Component Contributions - PHEV20

The Minimum / Maximum Of Individual Component Contributions Depend On The Order Of Technologies Modeled



Minimum benefit occur when all technical targets are ***simultaneously*** met

Technical Accomplishments

Summary of Individual Component Technology Benefits

Component		Split HEV	PHEV 20 miles	PHEV 50 miles	BEV 400 miles
Engine	% FC Improvement	15.2 – 18.5	16.6 – 19.4	17.7 – 21.8	
	% MSRP Reduction	2.1 – 10.5	1.8 – 9	1.6 – 7.7	
Battery	% FC Improvement	0	0.3 – 2.7	0.2 – 3.1	6.7 – 10.3
	% MSRP Reduction	3.3 – 11.5	12.4 – 22.3	19.9 – 30.9	37.7 – 48.3
Electric Machine	% FC Improvement	~0	~0	~0	~0
	% MSRP Reduction	10.3 – 19.8	9.5 – 17.8	9.4 – 16.7	3.7 – 4.9
Lightweighting	% FC Improvement	10.8 – 12.8	12.5 – 16.6	11.4 – 15.6	12.4 – 14.4
	% MSRP Reduction	-3.4 – -12.7	-0.9 - -9.9	-6.4 – 2	-0.4 – 4.7
Other	% FC Improvement	15.1 – 18.5	15.7 – 19.4	18.2 – 21.8	22.8 – 27.8
	% MSRP Reduction	2.2 – 10.5	4.1 – 13.5	6 – 16.2	12 – 20.6

MSRP Comparison With Commercial Vehicles

Most Autonomie Vehicle MSRP Within 10-15%

2018 Toyota Rav4 Hybrid XLE

	Unit	BaSce model	Matching commercial car	Relative difference
MSRP (RPE factor = 1.5)	$	(35619)	30000	- 16%
Unadjusted FE (city/hwy/comb)	MPG	43/42/42	45/42/44	Combined mpg: + 3.1%
Curb weight	kg	1826	1780	- 2.5%

2018 Jeep Grand Cherokee FWD

	Unit	BaSce model	Matching commercial car	Relative difference
MSRP (RPE factor = 1.5)	$	(31070)	31700	+ 2.0%
Unadjusted FE (city/hwy/comb)	MPG	22/30/27	23/34/27	Combined mpg: 8.4%
Curb weight	kg	2043	2062	0.9%

2018 Ram 1500 Regular Cab

	Unit	BaSce model	Matching commercial car	Relative difference
MSRP (RPE factor = 1.5)	$	(32665)	28419	- 13%
Unadjusted FE (city/hwy/comb)	MPG	21/27/24	20/32/24	Combined mpg: + 1.3%
Curb weight	kg	2026	2150	+ 6.1%

2018 GMC Sierra 1500 Double Cab

	Unit	BaSce model	Matching commercial car	Relative difference
MSRP (RPE factor = 1.5)	$	(32665)	36000	+ 10%
Unadjusted FE (city/hwy/comb)	MPG	21/27/24	20/30/23	Combined mpg: - 2.8%
Curb weight	kg	2026	2317	+ 14%

Performance requirements of trucks

Some of the values are still under review.

Class	Purpose	Regulatory Code	0-30mph (s)	0- 60mph (s)	Grade Speed (mph)	Percent Grade	Cruise Speed(mph)	Cruise Grade(%)	Max. Speed (mph)	Startablity (%)	Test Weight (lb)	90 percentile Daily Driving Range (miles)			
2	Van	Light_HD	7	21.5	65	6	70	1.5	75	15	10000	200			
3	PnD	Light_HD	9	30	50	6	70	1.5	75	15	14000	150			
3	Van	Light_HD	6.4	24	50	6	70	1.5	75	15	14000	200			
3	School	Light_HD	5.6	20	60	6	70	1.5	75	15	14000	150			
3	Service	Light_HD	5.8	18	65	6	60	1.5	65	20	14000	150			
4	PnD	Light_HD	9	30	50	6	70	1.5	75	15	16000	150			
4	WalkIn	Light_HD	7.5	35	40	6	70	1.5	75	15	16000	150			
5	Utility	Medium_HD	9	24	50	6	60	1.5	65	20	19500	150			
6	PnD	Medium_HD	14	40	40	6	60	1.5	65	15	26000	150			
6	Construction	Medium_HD	11.6	50	35	6	55	1.5	60	20	26000	150			
7	Tractor	DayCab_HR	18	60	30	6	65	1.25	70	15	33000	250			
7	Tractor	DayCab_MR	18	60	30	6	65	1.25	70	15	33000	250			
7	Tractor	DayCab_LR	18	60	30	6	65	1.25	70	15	33000	250			
7	Vocational	Medium_HD	18	60	30	6	60	1.25	65	15	33000	200			
7	School	Medium_HD	18.5	60	30	6	55	1.25	60	15	33000	150			
8	Tractor	Sleeper_HR	18	60	30	6	65	1.25	70	15	80000	500			
8	Tractor	Sleeper_MR	18	60	30	6	65	1.25	70	15	80000	500			
8	Tractor	Sleeper_LR	18	60	30	6	65	1.25	70	15	80000	500			
8	Tractor	DayCab_HR	20	66	30	6	65	1.25	70	15	80000	250			
8	Tractor	DayCab_MR	20	66	30	6	65	1.25	70	15	80000	250			
8	Tractor	DayCab_LR	20	66	30	6	65	1.25	70	15	80000	250			

Split up of trucks by class & vocation

- VIUS data, interaction with industry groups (21CTP), DOE technology managers & OEMs have guided the selection of vehicle classes and vocations in this work.
- The aim of this work is to include more and more vehicles to cover all major class/vocation combinations in this list. The circled cases are already modelled.

Fuel Use

rank	Class_body	million DGE	%	cumul %
1	8_Sleeper Cab	19,024.81	44.8%	44.8%
2	8_Day Cab	9,470.86	22.3%	67.1%
3	7_Day Cab	1,459.99	3.4%	70.6%
4	3_Pickup	1,238.28	2.9%	73.5%
5	8_Bus, nonschool	1,227.46	2.9%	76.4%
6	8_Dump	972.21	2.3%	78.7%
7	7_Bus, school	755.45	1.8%	80.5%
8	6_Box Truck	578.31	1.4%	81.8%
9	8_Refuse	455.21	1.1%	82.9%
10	7_Box Truck	433.25	1.0%	83.9%
11	8_Box Truck	370.55	0.9%	84.8%
12	4_Specialty Hauling	364.60	0.9%	85.7%
13	8_Specialty Hauling	359.32	0.8%	86.5%
14	4_Step/Walk-in Van	352.10	0.8%	87.3%
15	4_Utility Aerial	335.76	0.8%	88.1%
16	8_Concrete	335.10	0.8%	88.9%
17	6_Specialty Hauling	330.22	0.8%	89.7%
18	3_Van	318.98	0.8%	90.4%
19	7_Dump	239.42	0.6%	91.0%
20	4_Utility Non-aerial	214.25	0.5%	91.5%

Miles

rank	Class_body	million miles	%	cumul %
1	8_Sleeper Cab	109,324.0	41.0%	41.0%
2	8_Day Cab	53,286.2	20.0%	61.0%
3	3_Pickup	17,380.1	6.5%	67.5%
4	7_Day Cab	9,334.5	3.5%	71.0%
5	7_Bus, school	5,294.6	2.0%	73.0%
6	8_Dump	4,976.9	1.9%	74.9%
7	3_Van	4,768.7	1.8%	76.7%
8	8_Bus, nonschool	4,457.9	1.7%	78.3%
9	6_Box Truck	4,392.3	1.6%	80.0%
10	4_Specialty Hauling	3,686.4	1.4%	81.4%
11	8_Box Truck	3,202.9	1.2%	82.6%
12	4_Step/Walk-in Van	3,151.5	1.2%	83.7%
13	7_Box Truck	3,115.9	1.2%	84.9%
14	4_Utility Aerial	2,660.4	1.0%	85.9%
15	6_Specialty Hauling	2,357.7	0.9%	86.8%
16	8_Specialty Hauling	2,317.0	0.9%	87.7%
17	8_Refuse	2,061.1	0.8%	88.4%
18	4_Utility Non-aerial	1,993.1	0.7%	89.2%
19	5_Box Truck	1,480.1	0.6%	89.7%
20	7_Specialty Hauling	1,439.8	0.5%	90.3%

Population

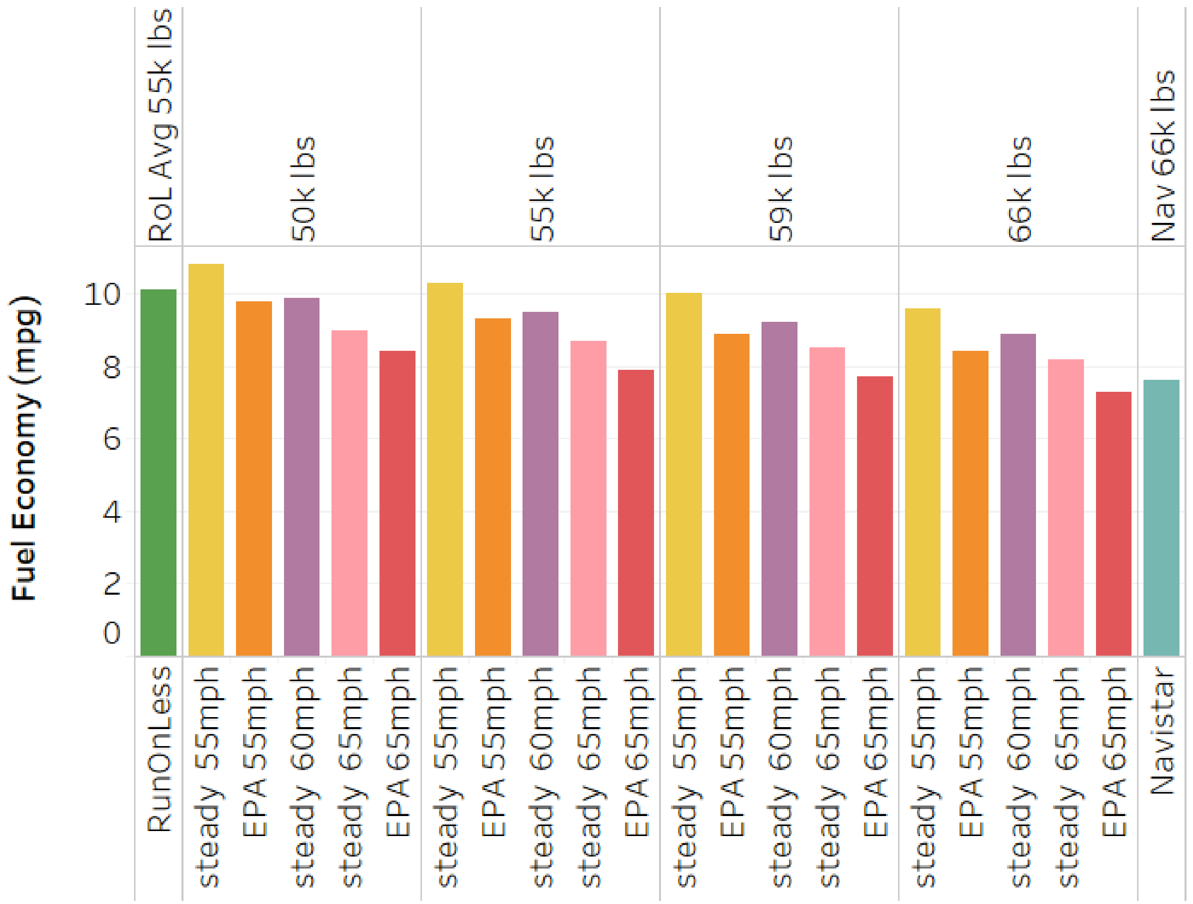
rank	Class_body	population	%	cumul %
1	8_Sleeper Cab	1305953	14.4%	14.4%
2	8_Day Cab	1091019	12.0%	26.4%
3	3_Pickup	929805	10.2%	36.6%
4	7_Bus, school	451361	5.0%	41.6%
5	3_Van	366297	4.0%	45.6%
6	6_Specialty Hauling	274335	3.0%	48.6%
7	8_Dump	272703	3.0%	51.6%
8	4_Specialty Hauling	266238	2.9%	54.6%
9	6_Box Truck	262879	2.9%	57.4%
10	7_Day Cab	212937	2.3%	59.8%
11	7_Box Truck	212163	2.3%	62.1%
12	6_Dump	198043	2.2%	64.3%
13	4_Utility Aerial	182505	2.0%	66.3%
14	8_Box Truck	179568	2.0%	68.3%
15	7_Dump	163937	1.8%	70.1%
16	7_Specialty Hauling	161203	1.8%	71.9%
17	8_Specialty Hauling	158335	1.7%	73.6%
18	5_Specialty Hauling	151257	1.7%	75.3%
19	4_Step/Walk-in Van	147939	1.6%	76.9%
20	5_Box Truck	140692	1.5%	78.4%

Vehicle statistics : courtesy J.Lustbader (NREL)

VERIFIABLE OPEN MODELS, CUSTOMIZABLE CONTROLS & TEST PROCEDURES

Simulation results are compared with reports from the industry for Class 8 Linehaul

- RunOnLess data was recorded from trucks that were running a variety of routes in US.
- Navistar published the fuel economy comparison of various trucks from tests conducted in a specific route in Canada.
- **Autonomie** simulations were done on multiple cycles with various vehicle test weights. Multiple cycles were evaluated in simulation, as the exact real world cycles were not available. RunOnLess results had average speed of 54mph. The simulations results at a steady 55mph and the EPA 55 cycle



International Prostar, MT-45, K-270, eNV200 were all modelled and verified as part of various projects over the past few years.

NET PRESENT VALUE OF COST OF OWNERSHIP (TCO)

Considers vehicle purchase price and fuel cost. Infrastructure, maintenance costs & wages are being added for some classes.

Assumptions for calculating Net Present Value of ownership costs

- Discount rate → 7%
- Service period of Sleepers are set to 5 years, rest of the vehicles are used for 15 years.
- Purchase price is estimated from Autonomie model, based on assumptions reviewed by DOE, 21CTP,…
- Fuel Cost :
  - Diesel → \$2.5 - \$4 per gallon
  - Electricity → 10c to 30c per kWh
- Annual VMT → class and vocation specific. Varies from 30k to 120k miles per year

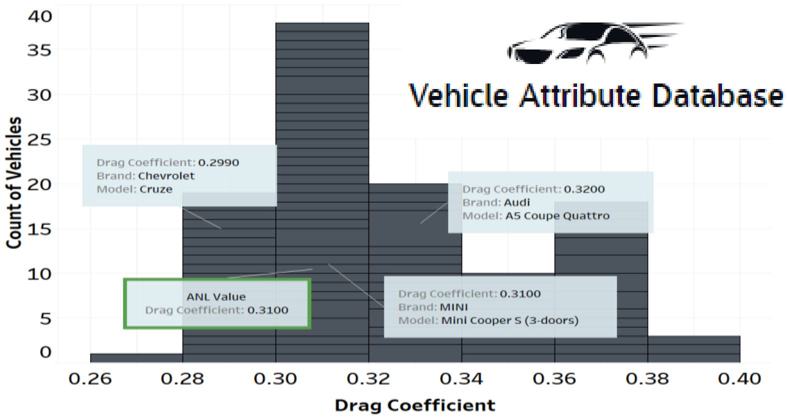
- **Validation Example:**
  - Autonomie estimates a Class 8 Sleeper truck to cost \$0.62/mile out of which \$0.39 is for the fuel
  - ATRI report confirms that this is a good estimate.

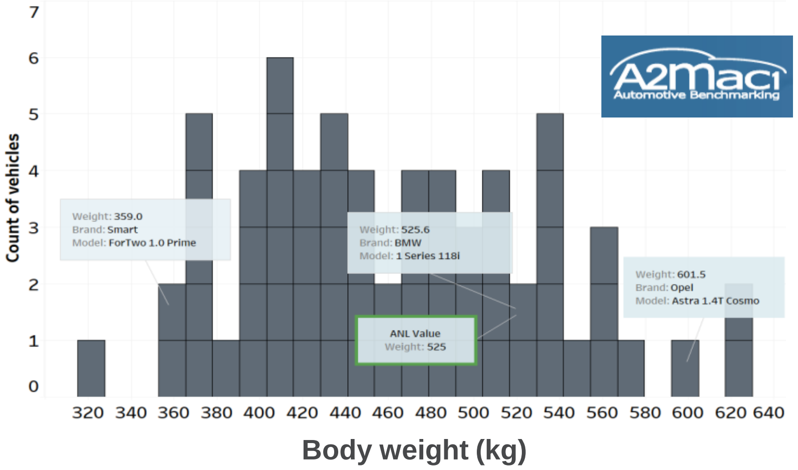
ATRI American Transportation Research Institute

Table 8: Average Marginal Costs per Mile, 2009-2017

Motor Carrier Costs	2009	2010	2011	2012	2013	2014	2015	2016	2017
Vehicle-based									
Fuel Costs	\$0.405	\$0.486	\$0.590	\$0.641	\$0.645	\$0.583	\$0.403	\$0.336	\$0.368
Truck/Trailer Lease or Purchase Payments	\$0.257	\$0.184	\$0.189	\$0.174	\$0.163	\$0.215	\$0.230	\$0.255	\$0.264
Repair & Maintenance	\$0.123	\$0.124	\$0.152	\$0.138	\$0.148	\$0.158	\$0.156	\$0.166	\$0.167
Truck Insurance Premiums	\$0.054	\$0.059	\$0.067	\$0.063	\$0.064	\$0.071	\$0.074	\$0.075	\$0.075
Permits and Licenses	\$0.029	\$0.040	\$0.038	\$0.022	\$0.026	\$0.019	\$0.019	\$0.022	\$0.023
Tires	\$0.029	\$0.035	\$0.042	\$0.044	\$0.041	\$0.044	\$0.043	\$0.035	\$0.038
Tolls	\$0.024	\$0.012	\$0.017	\$0.019	\$0.019	\$0.023	\$0.020	\$0.024	\$0.027
Driver-based									
Driver Wages	\$0.403	\$0.446	\$0.460	\$0.417	\$0.440	\$0.462	\$0.499	\$0.523	\$0.557
Driver Benefits	\$0.128	\$0.162	\$0.151	\$0.116	\$0.129	\$0.129	\$0.131	\$0.155	\$0.172
TOTAL	**\$1.451**	**\$1.548**	**\$1.706**	**\$1.633**	**\$1.676**	**\$1.703**	**\$1.575**	**\$1.592**	**\$1.691**

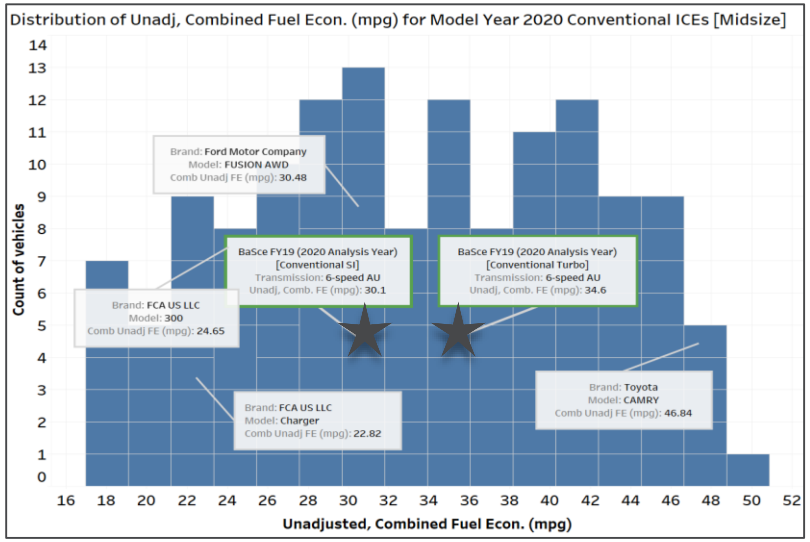
Reference Vehicle Attributes Selection





<u>Vehicle attributes (</u>Frontal area, Drag coefficient, Rolling resistance, Final drive ratio, Gear span…)

<u>Weights (</u>Body, Chassis, Safety, Interior, Gearbox, Final drive…)



★ BaSce FY19 value

MSRP Comparison With Commercial Vehicles

Most Autonomie Vehicle MSRP Within 10-15%

2017 Chevrolet Sonic

	Unit	BaSce model	Matching commercial car	Relative difference
MSRP (RPE factor = 1.5)	$	(18957)	15070	- 21%
Unadjusted FE (city/hwy/comb)	MPG	31/41/36	31/50/38	Combined mpg: + 6%
Curb weight	kg	1320	1240	- 6.1%

2016 Toyota Prius C

	Unit	BaSce model	Matching commercial car	Relative difference
MSRP (RPE factor = 1.5)	$	(24166)	24040	+ 0.5%
Unadjusted FE (city/hwy/comb)	MPG	58/56/57	72/70/71	Combined mpg: + 24%
Curb weight	kg	1378	1148	- 17%

2016 Ford Fusion

	Unit	BaSce model	Matching commercial car	Relative difference
MSRP (RPE factor = 1.5)	$	(29930)	31110	+ 4%
Unadjusted FE (city/hwy/comb)	MPG	28/39/33	28/48/35	Combined mpg: + 6.4%
Curb weight	kg	1595	1556	- 2.4%

2018 Kia Sorento LX

	Unit	BaSce model	Matching commercial car	Relative difference
MSRP (RPE factor = 1.5)	$	(27104)	27200	+ 0.4%
Unadjusted FE (city/hwy/comb)	MPG	27/35/31	27/40/31	Combined mpg: + 1.8%
Curb weight	kg	1636	1736	+ 6.1%